

GEMINI: First of a New Breed

FEBRUARY 1985 VOL. 7 NO. 2

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THE JOURNAL OF INTELLIGENT MACHINES

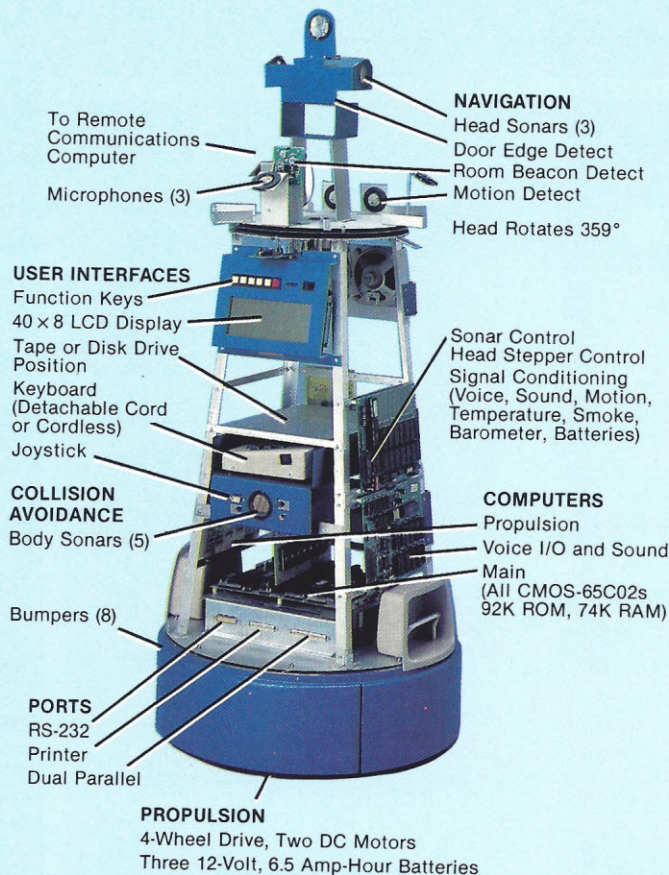
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ROBOTICS AGE—[ISSN 0197-1905] is published monthly by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, NH 03458, phone (603) 924-7136. Address subscriptions, changes of address, USPC Form 3579, and fulfillment questions to *Robotics Age* Subscriptions, 174 Concord Street, Peterborough, NH 03458. Second class postage paid at Peterborough, NH and at additional mailing offices. **POSTMASTER:** Send address changes to ROBOTICS AGE, 174 Concord St., Peterborough, NH 03458.

Subscriptions are \$24 for one year (12 issues), \$45 for two years (24 issues), \$63 for three years (36 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are \$28 for one year, \$53 for two years, \$75 for three years. For other countries, subscriptions are \$32 for one year, surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is \$3 in the U.S., \$3.50 in Canada and Mexico, \$4 in Europe, and \$4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

Address all editorial correspondence to the Editor at *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, NH 03458. Opinions expressed by the authors of articles are not necessarily those of *Robotics Age*. To aid in preparation of acceptable articles, an Authors' Guide is available upon request, if accompanied by a self-addressed 8½ by 11 inch envelope with first class postage for 3 ounces. Unacceptable manuscripts will be returned if accompanied by a self-addressed envelope with sufficient first class postage. Not responsible for lost manuscripts or photos.

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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

FEBRUARY 1985

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About the cover: We recently were introduced to Gemini, one of a new breed of personal robot conceptions with emphasis on multiprocessor computer design, low-power electronics, and an electro-mechanical experimenter's point of view. Gemini illustrates why the personal robot is a functional prototype for solutions to many of the design and application problems of modern robotics technology. Turn to page 12 for more details.

FAREWELL TO STEP COUNTERS

BY RAYMOND GA COTE

This month's cover story (see p. 12) has a picture of the Gemini robot from Artec, the first of a new generation of robots. What makes this new generation different? Granted it has more processing power than previous commercially available robots (each sub-function has its own processor) and it also has more sensory information available than anything else yet to arrive. However, this is not what rates the next generation label.

Gemini is the first commercially available machine to actually move from place to place and go through doors without counting steps. Up to now, telling a robot to move from one room to another required the robot to remember how many steps it was between the two rooms. This could drive the control software absolutely crazy when it found an object blocking its path.

At the recent personal robotics session at the Robots-West show, Gene Oldfield spoke about *goal-driven* robot systems. His belief is that robot programmers should spend less time worrying about *avoiding objects* and spend more time trying to *attain goals*. Gene's ideal navigational goal is a doorway. He observed that people moving about a house always aim at doors. A room without visible doors is very disturbing and can produce an uneasy feeling in many people—a feeling of being trapped. Thus, Gene theorizes, a robot should be designed to seek out doors and move through them just like a person.

This is what the Gemini designers have developed, a door-seeking robot. The current design requires an active infrared room beacon in each room and a passive infrared reflector at each door. These are used to present convenient room markers. People also work with room markers. Anyone who

has walked through a hall of mirrors at an amusement park knows the disorientation that occurs when all the rooms look identical and the doors are difficult to find. At this stage of technology, a robot operating without some sort of beacons and door markers is akin to a person wending their way through a hall of mirrors.

Yes, someday the robots will be sophisticated enough to determine what room they are in just by looking around. Until then, we've at least seen the next step in robot evolution where they don't have to keep track of every step they have made. I'm glad the days of the step-counting robots are numbered.

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February 1985

4-5 February. Industrial Modernization Strategies and Technologies. Don Ce Sar Hotel, St. Petersburg Beach, FL. Contact: Wendy Engelberg, Frost & Sullivan, Inc., 106 Fulton St., New York, NY 10038, telephone (212) 233-1080.

Frost & Sullivan in conjunction with Science Applications International Corp (SAIC) has organized the second annual Automated Manufacturing Conference. This year's event is organized around four half-day sessions: Strategies that User Companies are Employing; The Importance of Data Processing and Communications; Technologies (e.g., robotics, CAD/CAM, materials handling) for Industrial Modernization; and case histories. The program is designed for both users and vendors of automated manufacturing equipment.

11 February. Artificial Intelligence and Expert Systems. Marriott/Copley, Boston, MA. Contact: Lee Burgess, Rensselaer Polytechnic Institute, Troy, NY 12181, telephone (518) 266-6589.

This Executive Briefing session is designed by senior management for senior management personnel. It will provide the basic information needed to make decisions about when and where to use AI/ES in your products and processes.

21 February. An Overview of Robotics. Montclair State College, Upper Montclair, NJ. Contact: Professor Max Sobel, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4230.

This talk, conducted by Dr. Robert Dorner, Montclair State College, is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

25-28 February. Agri-Mation I. Palmer House Hotel, Chicago, IL. Contact: SME Public Relations, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

The three-day exposition will feature demonstrations of a wide range of automated equipment used in the production of food, fiber, and biomass materials. Featured will be new developments in irrigation and drainage, field equipment, material handling, storage and distribution, harvesting, processing, and the latest in computerized systems and services available to the agricultural manager, researcher, and engineer. Among the agricultural automa-

tion products on display will be data acquisition systems, measurement instruments, mobile robots, motors, programmable controllers, robotic components and systems, sensors, controls, transducers, and actuators.

March 1985

4-6 March. FutureCare. The Gunter Hotel, San Antonio, TX. Contact: The University of Texas, Health Science Center at San Antonio, Occupational Therapy Program, 7703 Floyd Curl Drive, San Antonio, TX, 78284, telephone (512) 691-7555.

FutureCare is a three-day conference concerning the role of technology in rehabilitation. The Symposium allows clinicians using the new technologies in rehabilitation to share their ideas, experiences, and research with others, while providing a forum for the exploration and discussion of a broad range of technological applications to clinical rehabilitation. Topics include cognitive rehabilitation, use of robot systems, patient evaluation and treatment, and computer-assisted instruction.

11-14 March. National Design Engineering Show. McCormick Place, Chicago, IL. Contact: Show Manager, National Design Engineering Show, 999 Summer St., Stamford, CT 06905, telephone (203) 964-0000.

19-20 March. Robotic End Effectors: Design and Applications Seminar. Holiday Inn Livonia-West, Livonia, MI. Contact: John McEachran, Special Programs Department, RI/SME, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, extension 382.

This seminar will give comprehensive coverage to robotic end effector design techniques, sensors for tooling, compliant devices, interchangeable end-of-arm tooling devices, multihand tools, and magnets for tooling. A number of case-study presentations will look at robotic end effectors for assembly, material handling, machine loading, metal cutting, and welding robotic systems. An added feature will be end effector vendor tabletop displays.

21-22 March. Computers and Young Children. University of Delaware, Newark, DE. Contact: Dr. Richard B. Fischer, Division of Continuing Education, University of Delaware, Newark, DE 19716, telephone (302) 451-8838.

This is the second national conference sponsored by the University of Delaware. The con-

ference explores the opportunities and problems educators face as computers are introduced into educational programs. The emphasis is on programs for children 4-8 years old.

26 March. Applications of Industrial Robots. Montclair State College, Upper Montclair, NJ. Contact: Professor Max Sobel, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4230.

This talk, conducted by Arnold L. Kelman, ASEA Robotics, Inc., is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

26-28 March. Vision '85. Cobo Hall, Detroit, MI. Contact: Jeff Burnstein, Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

Vision '85 will be the first major exhibition of machine vision systems and related equipment ever held. A comprehensive technical conference will accompany the show. Over 75 exhibitors are expected to demonstrate the latest in vision technology. The exposition will feature the latest in assembly, inspection, related vision components, computerization technologies, robotics, software, part identification, and sensors. Also featured will be parts assembly, material handling, work-in-progress, warehousing, guidance, and control technologies with vision capabilities. RIA's sponsorship of Vision '85 is an outgrowth of the trade association's new emphasis on machine vision.

26-28 March. ARTELL '85. Philadelphia Civic Center, Philadelphia, PA. Contact: ARTELL '85 Conference Headquarters, Access Conference Associates, Inc. PO Box 160, Gaithersburg, MD 20877, telephone (301) 921-9424.

ARTELL '85 will be a premier national and international educational and marketing forum for the manufacturer, design engineer, distributor, and end-user involved in the development, pioneering research, marketing, and universal application of artificial intelligence systems and software. The estimated audience of 2,500 attendees will be primarily attracted from the AI academic sciences and the design engineering divisions of major national and international corporations committed to the specialized area of AI engineering systems expertise. Program topics include vision, robotics, expert systems, automated reasoning,

knowledge representation, speech and natural language understanding, search and learning, and planning and problem solving.

April 1985

8-12 April. SPIE's Technical Symposium East '85. Hyatt Regency Crystal City Hotel, Arlington, VA. Contact: SPIE, PO Box 10, Bellingham, WA 98227, telephone (206) 676-3290.

SPIE—The International Society for Optical Engineering—will conduct a symposium covering topics ranging from photovoltaic technology to artificial intelligence applications. Of particular interest are the sessions titled "Applications of Artificial Intelligence II" and "Sensor Design Using Computer Tools II." The AI II session will discuss image understanding, expert systems, robot vision, computer vision, autonomous navigation, autonomous vehicles, and contextual scene analysis. The Sensor Design II session will discuss the design of imaging and nonimaging sensors for all spectral regions, design of sensor subsystems and support sys-

tems, and applications of personal computers to design, testing, and modeling.

17-24 April. Hanover Fair. Hanover, West Germany. Contact: Delia Associates, PO Box 338, Whitehouse, NJ 08888, telephone (201) 534-9044.

The 1985 Hanover Fair will place special emphasis on mechanical and fluid power transmission, controls, and industrial parts handling. A separate sector of the fair has been set up to accommodate pertinent exhibits.

18-21 April. FutureWorld Expo. Moscone Center, San Francisco, CA. Contact: FutureWorld Expo, 940 Emmett Ave., Suite 14, Belmont, CA 94002, telephone (415) 595-2708.

FutureWorld is a unique marketplace for presenting new ideas, new technologies, new products, and visions of our world to come. Exhibited products include robots, computers, new automobile innovations, and the latest in fashion and home design.

19 April. Developments in Japanese Robots. Montclair State College, Upper Montclair, NJ.

Contact: Professor Max Sobel, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4230.

This talk, conducted by Mark Llangenfeld, Hitachi America, Ltd., is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

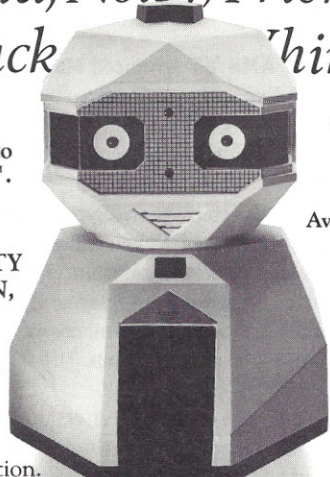
22-25 April. LASERBOTICS: Combining Laser and Robot Technologies. Ann Arbor, MI. Contact: Steve Palma, SME Special Programs Department, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

The program will feature speakers from the U.S., Europe, and Asia and will examine the latest advancements in the science of combining lasers and robots to improve productivity. Co-chairperson Jack Lane, director of the Robotics Center at the GMI Engineering and Management Institute, and David Belforte, president, Belforte Associates, are preparing an agenda covering the latest advancements in laser tooling, robotic part presentation, laser-guided robotics, fiber optics, laser/robot welding and inspection.

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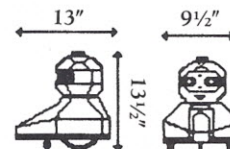


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23-24 April. 1985 Conference on Intelligent Systems and Machines. Oakland University, Rochester, MI. Contact: Professor Nan K. Loh, Conference Chairman, Center for Robotics and Advanced Automation, School of Engineering and Computer Science, Oakland University, Rochester, MI 48063.

Technical papers reflect both advances and applications in all aspects of intelligent systems and machines. Suggested topics include: intelligent robots, machine intelligence, adaptive control and estimation, visual perception, artificial intelligence for engineering design, intelligent simulation tools, computer-integrated manufacturing systems, knowledge representation, expert systems, game theory and military strategy, interpretation of multisensor information, and automatic programming.

30 April, 1-2 May 1985. Artificial Intelligence and Advanced Computer Technology. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

AI '85 will be a commercial applications event presenting the latest developments in the many aspects of artificial intelligence, including natural language systems, expert systems, visual recognition systems, automatic programming, and the new generation of computer hardware to house the new technology.

May 1985

8 May. Simple Solutions to Complex Robot Applications. Montclair State College, Upper Montclair, NJ. Contact: Professor Max Sobel, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4230.

This talk, conducted by Michael T. McCraley, Panasonic Industrial Co., is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

June 1985

18-20 June. AMS '85 Advanced Manufacturing Systems Exposition & Conference. O'Hare Exposition Center, Rosemont, IL. Contact: Cahners Exposition Group, Stamford, CT.

24-27 June. 4th International Symposium on Unmanned, Untethered, Submersible Technology. University of New Hampshire, Durham, NH. Contact: Dick Blidberg, Marine Systems Engineering Laboratory, University of New Hampshire, PO Box G, Durham, NH 03824, telephone (603) 749-6056.

This symposium is focused directly on the programs and technologies in the field of unmanned, untethered submersible systems. The symposium is meant to provide background and insight related to this developing technology. The emphasis is to stimulate informal interaction among participants. In addition, a one-day classified session is planned. Anyone planning to submit papers for this symposium should provide abstracts by March 1.

July 1985

15-19 July. PC'85. Olympia 2, London, England. Contact: Evan Steadman Services,

Ltd., The Hub, Emson Close, Saffron Walden, Essex CB10 1HL, telephone 0799 26699.

PC'85 is Europe's first exhibition and conference devoted entirely to programmable controllers and systems. The conference will focus on the rapid advances in the programmable controllers field, emphasizing the increasing power and capabilities of programmable controllers. Conference topics include programmable controllers linked with personal computers, communication and distribution control, graphics, languages, and documentation.

22-26 July. SIGGRAPH '85. San Francisco, CA. Contact: SIGGRAPH '85 Conference Services Office, 111 East Wacker Dr., Chicago, IL 60601, telephone (312) 644-6610.

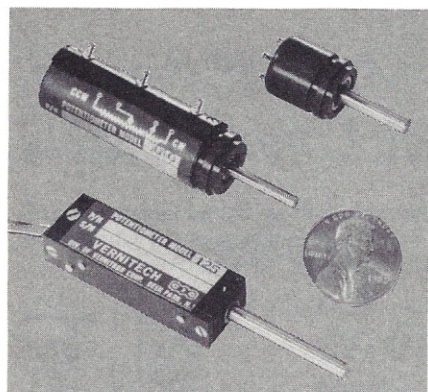
A wide variety of one- and two-day courses will be presented. The conference forum will provide a unique opportunity to explore topics of special interest in parallel with the formally refereed papers. An art show along with a film and video show will also be included at the conference. SIGGRAPH '85 is sponsored by the Association for Computing Machinery's Special Interest Group on Computer Graphics in cooperation with Eurographics and the IEEE Technical Committee on Computer Graphics.

September 1985

23-25 September. Space Tech '85. Disneyland Hotel, Anaheim, CA. Contact: Tom Akas, SME, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

"Space Technology—Engineering for Space Industrialization and Utilization" is the theme for this three-day conference that will focus on new engineering technologies and solutions that are required to make space industrialization practical and economical for a variety of industries. Conference topics will span the spectrum of telecommunications, materials, computerization, and manufacturing. Running concurrently with the conference will be an exposition featuring materials, equipment, and technologies pertinent to engineering and manufacturing in space. The conference is jointly sponsored by the Aerospace & Electronic Systems Society of IEEE, the American Society of Mechanical Engineers, the American Society of Metals, the American Society for Quality Control, the Computer and Automated Systems Association of SME, the Computer Society of IEEE, the Industrial Electronics Society of IEEE, Robotics International of SME, and the Society of Manufacturing Engineers.

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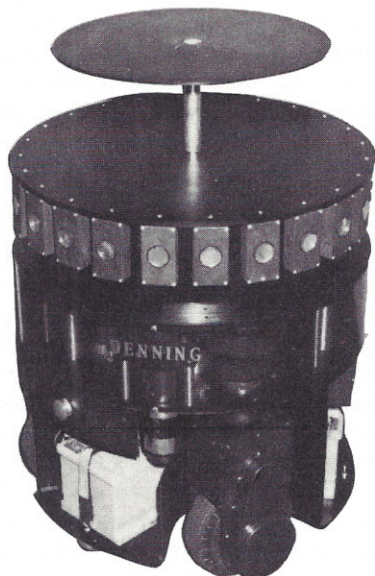
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Sensory Perceptions

RESEARCH VEHICLE. Denning Mobile Robotics of Woburn, MA has recently announced the availability of a mobile robotics research machine. The Model T is strong (carries up to 200 lbs. of equipment), maneuverable (can turn on its axis), and relatively quick (3 mph under ultrasonic guidance) for a mobile robot. The research vehicle is round with a 27 in. diameter to fit through a standard 30 in. doorway. The Model T employs a three-wheel synchronous drive and steer system which allows for ease of maneuvering and control. The 380 lb. robot includes a Z80-based ultrasonic object-avoidance and pathfinding capability. A total of 24 Polaroid ranging devices are arranged in a circle at a height of 29 in. for optimum object detection.



Motor and steering control is accomplished by a separate Z80-based expert module. A 68008 board with 128 Kbytes of memory running the OS-9 Unix-like operating system is standard for data processing. Dual differential line drivers provide RS-422 internal communication over a synchronous data link on a serial multi-drop backplane. RS-232 is included for external communication.

The first unit was shipped in November 1984 to Dr. James Crowley at the Carnegie-Mellon Robotics Institute. Dr. Crowley is using the vehicle in his autonomous ultrasonic map-making work.

SPEECH RESEARCH. Scott Instruments Corp. has been awarded a Phase I research contract from the National Institute of Health (NIH). Scott Instruments will be developing a line of software packages for the speech-language-hearing profession. The NIH research will deter-

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Sensory Perceptions

mine the feasibility of using a microcomputer-based therapy system which incorporates speech input and output to treat communication disorders. Scott Instruments has also conducted research for the NIH in the development of a tactile aid for the deaf.

WELDING VISION. Advanced Robotics Corp. and Ohio State University have joined resources to develop a vision-equipped arc-welding robotic work cell for NASA. The work cell will be used to weld Space Shuttle engine parts. The vision system will be placed in the welding head to produce a compact system protected from heat and smoke while also providing a clear view of the weld pool.

SIEMENS RESEARCH. The Research and Technology Laboratories (RTL) Division of Siemens Corporate Research and Support, Inc. has been established at the Princeton Forrestal Center as the U.S. arm of the Siemens Corporate R&D complex. According to Dr. Karl H. Zaininger, executive vice president, RTL is dedicated to the exploration of such technologies of tomorrow as artificial intelligence, touch, vision and hearing. The Princeton-based

laboratory will also investigate expert systems, robotics, software technology, distributed computer systems, VLSI design automation, and microelectronics.

CHEAPER SPEECH. Votrax, Inc. has reduced prices of the SC01 voice synthesizer chip to \$32 in unit quantities. The SC01 phonetically synthesizes continuous speech by combining phonemes in the appropriate sequences. The chip contains 64 different phonemes that are accessed by a six-bit code.

BOOKS OF NOTE. The following is just a sampling of the books that have passed our way recently.

The *Everyone Can Build a Robot Book* by Kendra Bonnett, Gene Oldfield, and the editors of Digit Magazine provides a wonderful overview of robot history and technology along with diagrams, parts lists, and detailed instructions for constructing a robot. Aimed at readers 14 years and older, this book is a delightful introduction for children. The reader receives complete plans on how to build a Moth, a light-seeking robot. The basic Moth is a three-wheeled vehicle made from common com-

ponents that will seek out a light source. Although the first model is not computer controlled, a more intelligent second version adds a communications port that allows users to control the robot from another computer, thus creating a robot turtle. A must for any child interested in what robots are and how they can be built.

The *Everyone Can Build a Robot Book* is published by the Computer Book Division of Simon & Schuster, ISBN 0-671-53059-3.

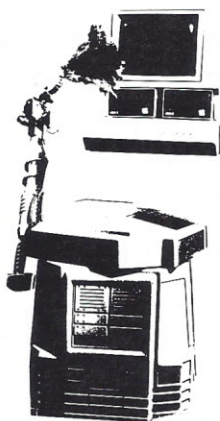
Now that you've got one, how do you fix it? *Electronic Servicing of Robotic Equipment* by Joel Goldberg provides basic concepts for robot repair. The book provides basic electrical theory, elementary analysis and troubleshooting, and information regarding electrical systems in general. The only specifically robot-related section is the chapter on servosystems. Although not specifically useful for the technician or repairperson familiar with other computer-based systems, the book would serve as a good introductory text in a robot technicians course. Unfortunately, all the diagnoses and repair tips focus on the robot electronics; there is only passing mention of robot mechanics and how it relates to the electronics.

Electronic Servicing of Robotic Equipment is published by Prentice-Hall, ISBN: 0-13-252131-8.

Stepping Motors: A Guide to Modern Theory and Practice by P. P. Acarnley provides an in-depth look at the driving force behind many of today's industrial and experimental motors. The book starts with a general overview of stepping motor technology and quickly delves into detailed engineering discussions of drive circuits, static torque characteristics, torque/speed characteristics, and high-speed operation. Individual chapters are devoted to the topics of open-loop and closed-loop control. The closing chapter discusses microprocessor-based stepping motor systems. Although I would have liked to see a more thorough discussion of microprocessor control, the author does manage to cover open- and closed-loop software control with example algorithms for stepping control, ramping acceleration and deceleration, and switching angle control. This book will provide a wealth of information for the designer needing to know detailed stepping motor techniques as well as the newcomer looking for an overview of stepping motor technology.

Stepping Motors: A Guide to Modern Theory and Practice is published by Peter Peregrinus, Ltd. on behalf of the Institution of Electrical Engineers, ISBN: 0-906048-75-3.

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THE SANDI PROJECT

Mitchell Alexander
New York Institute of Technology
Robotics Research Laboratory
Old Westbury, NY 11568

Sandi began as a seminar project in 1980. Over the course of two years, various students designed and built Sandi's mobile base and hydraulic/electric arm. When the New York Institute of Technology faculty realized Sandi's capabilities, they created a center for Robotics Research and Artificial Intelligence. Since the lab opened, students have completed work on Sandi's central processing computer, ultrasonic ranging systems, avoidance and motion control algorithms, a DC servoamplifier, a hydraulic servosystem and a remote-control box.

Several guidelines have been established to help focus the students' ideas. The overall purpose of the project is to build a mobile, general-purpose robot with its own computer, power supply, and necessary sensors. Some initial goals were established to expedite the design process:

- Sandi must fit through a standard industrial door.
- Sandi's weight cannot exceed 800 lbs. (360 kg).
- The base must be able to surmount a 2 in. (50 mm) obstacle.
- Sandi must be able to operate on soft and uneven surfaces.
- The gripper payload capacity must exceed 110 lbs. (49.5 kg).
- The base must be watertight (to prevent contamination from rain, chemical waste spills, etc).
- The maximum tractive effort should be 400 lbs. (1779 N).
- The maximum speed need not be greater than 10 mph.
- Each software module should have its own slave processors which will plug into the central processing computer.
- High-level tasks should be resolved into simpler tasks for lower levels.
- Each module should be individually testable with a standard ASCII terminal.

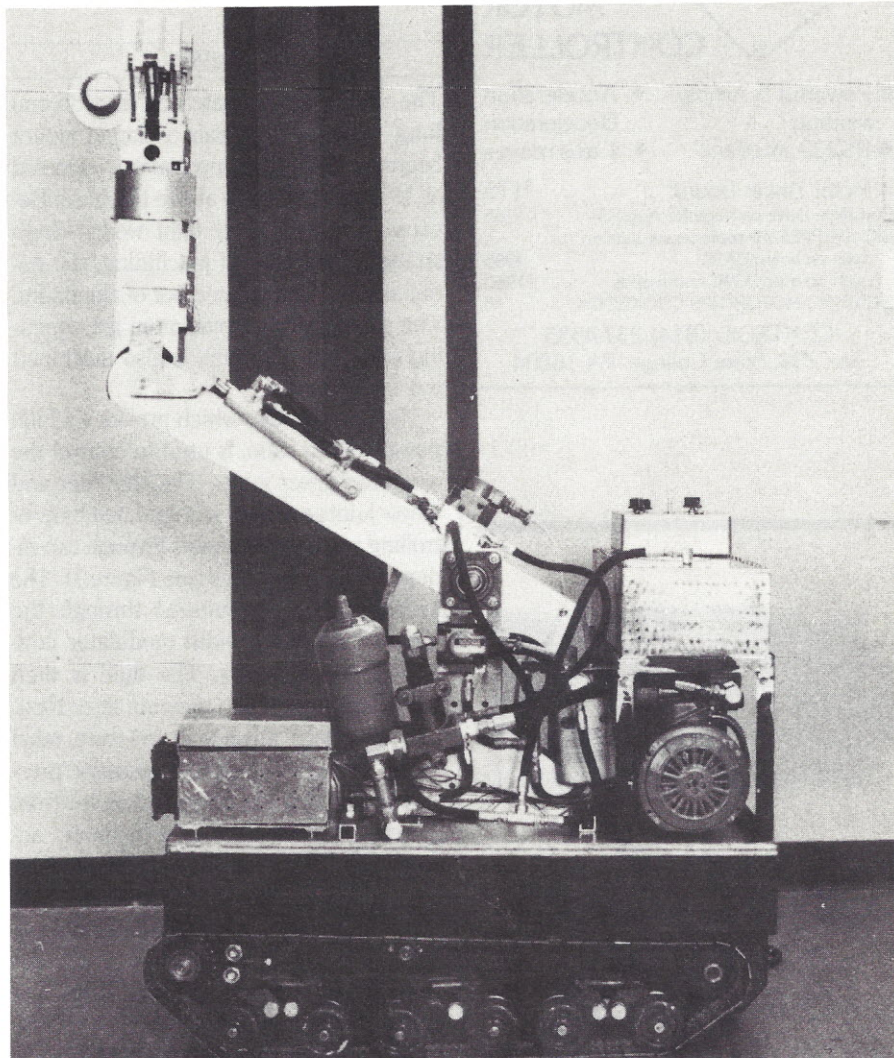


Photo 1. An overview of the tracked Sandi vehicle. The 700 lb. base can move through a standard industrial door and lift 100 lbs. with its gripper.

BASE DESIGN

The base is constructed of welded plate steel. This gives the arm a sturdy foundation. The drive train consists of two 1.3 hp DC servomotors running through variable automatic transmissions, which are linked to the crawler-type treads through a reliable sprocket and chain system. These transmissions were chosen because of their

ability to select the best gears for the fastest speed or highest torque. The necessary suspension is handled by coil springs and swing arms. This type of suspension, coupled with the treads, allows the base to travel on smooth as well as rough surfaces. Stopping power is provided by electro-mechanical brakes.

The base also houses Sandi's two independent power supplies. One supply is

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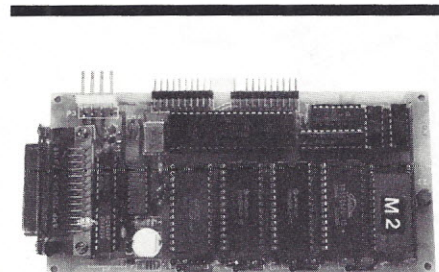
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48 V, which is used to power the motors. The other is 12 V, which is used to power all of Sandi's computer and control systems. Rechargeable gel-type batteries are used because of their fast charging time and low cost.

The base is covered with aluminum-skinned $\frac{3}{4}$ in. (19 mm) marine plywood. This acts as the mounting surface for many of the torso components, as well as the hydraulic/electric arm. This material was chosen for its strength and for the ease with which items can be mounted on it.

ARM DESIGN

The arm is approximately 54 in. (135 cm) long. It pivots on a pair of flange mount bearings which are approximately centered at 15.5 in. (388 mm) above the base. Because of its relatively light weight, high strength, and ease of machining, the entire arm was constructed out of aluminum. The gripper, with a maximum grip opening of 4.5 in. (113 mm), is also machined out of aluminum.

Hydraulic power, which provides a high power-to-cost ratio, is used to control the arm's two lower joints. The shoulder and elbow joints are both manipulated by controlling two hydraulic rams through two independent servovalves (see Figure 1). The hydraulic fluid is pumped through the system by a pulse width modulator controlled, $\frac{3}{4}$ hp motor. The fluid is then passed through a high-pressure filter. Next, the oil passes through a pressure relief valve. This valve opens on excessive pressure, protecting the pump and motor from damage. Next in line is a hydraulic accumulator. This maintains the proper fluid and pressure level in the system at all times. It operates in much the same way that capacitors do on a circuit card to insure that the supply voltage does not decrease when logic gates are switching. In short, it is a pressurized storage tank. From this point the fluid divides to go into the input of the two servovalves. The servovalves provide the correct fluid pressure for the hydraulic rams. The returning oil then passes through a low-pressure, 33 micrometer filter to insure that debris does not pass into the 5 gallon (19 l) storage tank.

The remaining two arm joints are powered by electric motors. These two joints require a more precise alignment and feedback than the other two. The wrist

rotation is powered by a geared DC pancake servomotor. Position sensing data comes from an incremental optical encoder mounted on the wrist rotation shaft. The gripper motor is a unipolar stepper motor with a holding torque of 36 oz-in. (254 mNm) with a step angle of 7.5 degrees. The stepper motor goes through a series of torque multiplying gears, before activating the parallel aluminum jaw gripper.

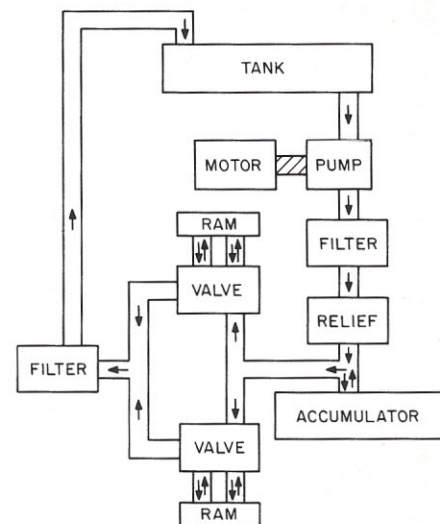


Figure 1. Sandi's hydraulic system.

COMPUTER AND SENSOR DESIGN

At the heart of Sandi's central processing unit is the Motorola 6801 microprocessor. All of Sandi's algorithms and operating systems have been written and debugged on a Millenium development in-circuit emulator system. This system has sped up development time as well as solved some fairly difficult problems. A major timesaver was the ability to write all source code in PLMX which is a powerful, but easy to learn, language.

Sandi's powerful central processing unit collects data from a Polaroid ultrasonic transducer and driver board. The transducer is mounted on an oscillating motor in much the same way that radar antennae are scanned. Sandi has the ability to sense an obstacle in its path, decelerate, or, if the obstacle is too close, perform an emergency stop, maneuver itself around the obstacle, and then accelerate away from it. There are provisions for up to four transducers to operate simultaneously.

An interesting piece of software that has recently been incorporated into Sandi's operating system is a *goal seeking* pro-

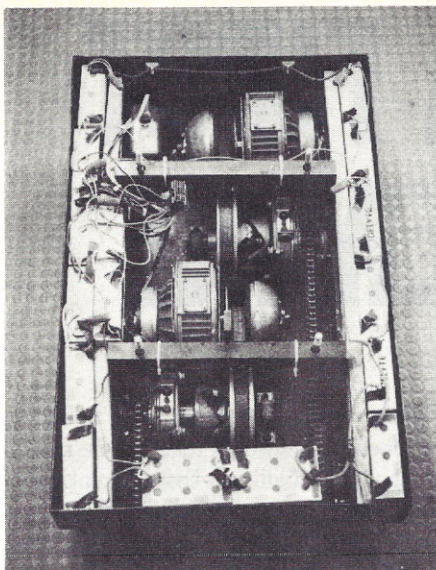


Photo 2. Close-up of Sandi's interior. The gel-cell batteries are mounted around the perimeter of the base. The two motor/transmission/clutch assemblies are also visible.

gram. Using the obstacle and accelerate/decelerate routines, Sandi can navigate towards a modulated light source of a specific frequency. This allows Sandi to find specific areas while avoiding obstacles in its path.

SERVOAMPLIFIERS

After experiencing various difficulties with a readily available commercial servoamplifier (we managed to burn it out due to some logic timing problems), we decided to design our own amplifiers with components that are rated at a minimum of 75 percent over the required voltage and current levels. The amplifiers have two input channels: one for the remote control box and one for the tachometer feedback signal. Current limiting is monitored by a current sensing circuit on the output stage. Under-voltage protection is included to insure that excessive current is not drawn from a weak battery supply.

The logic circuitry uses low power CMOS components, which switch the transistors at an inaudible 20 kHz. The traditional H-Bridge design output stage was chosen for its proven reliability and fast switching time. Lock-out circuitry insures that the forward and reverse transistors cannot be switched on simultaneously. Power-up protection circuitry insures that the output stage is not active when power is first supplied to the logic circuitry. Inex-

pensive bipolar output and driver transistors are used throughout the amplifier.

RESULTS

Thus far, the Sandi project has met its goals and has stayed within the constraints of the established guidelines: the gripper can lift 100 lbs. (45 kg), Sandi can move at about 5 mph (8 kph), and the unit weighs approximately 700 lbs. (315 kg).

This type of robot can be used for many applications, including nuclear power plant surveillance and maintenance, part transportation in warehouses, bomb disposal, teleoperated or autonomous military reconnaissance, and for basic research on artificial intelligence.

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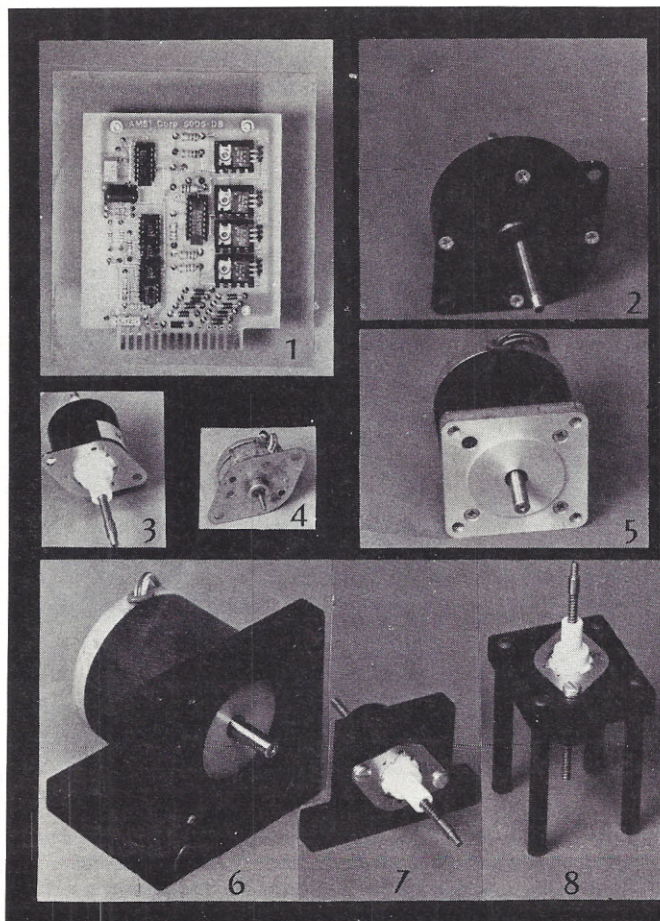


PHOTO ESSAY: A FIRST GLIMPSE AT GEMINI

BY CARL HELMERS

We recently had the opportunity to visit Jack Lewis and his crew in Columbia, Maryland to view the first of a new line of autonomous robots. Given the name "Gemini," this class of wheeled canister robots from Arctec Systems, Inc. is a significant step forward in the practical design of autonomous vehicles for research, practical personal use and experimentation. The Gemini-class machines will be of great interest to those who want to learn about and experiment with the use of today's concept of the self-feeding, self-powered autonomous platform robot.

We observed Gemini in operation in both prototype and final forms, exhibiting complicated and reliable motion behaviors, including transit from one room to another and return to the starting point. This robot uses principles of free vehicle navigation derived from marine and aviation practice rather than attempts to memorize an open-loop trajectory on uncontrolled floor surfaces. Using a beacon system together with door markers, Gemini can measure positions, triangulate and determine an attempted path to reach a selected goal. Bump, collision and object-presence sensing allows it to seek paths around obstacles using feedback rather than a memorized trajectory. Gemini may be the first practical self-feeding robot as it returns to a battery charger station always placed under a specific room marker beacon.

An optical system is used to sense beacons. An active reflective infrared optical system is used to locate door markers. When given the task of going from room N to room M, Gemini uses a stored connectivity map to count door markers relative to room N's beacon, then positions itself approximately near the selected door, sidles up to the vicinity of the door to fix the precise physical opening with its sonar, does a final shuffle to make sure it is in the right place, and then cruises through the doorway. This maneuver—all with ac-

tive sensors—takes several minutes to accomplish. The time is used mainly to accomplish mechanical scanning by the rotating turret sensor. (Clearly, an all-solid-state sensing approach would improve the speed by eliminating the mechanical scanning requirement. According to Jack, the CMOS version of a 6502 used in the navigation problem is using only a few percent of its computational bandwidth. In radar system engineering, the most advanced radars use solid-state scanning methods for exactly that reason—at a much higher cost.)

The system concept for Gemini is best illustrated by photographs. Photo 1a shows the pre-production prototype of Gemini with its clothes on. Photo 1b shows Gemini with its clothes off, with Jack pointing to one of the electronics boards. The machine's computational design uses a multi-processor, all CMOS approach to conserve

battery power. There are only a limited number of watt-hours that can be stored in the three batteries that Gemini uses. One 65C02 computer is the main computer orchestrating all operations. A backplane bus similar to the Apple II bus allows one to plug in extra peripherals. (The "similar" nature of the bus means that care must be taken to pay attention to power requirements and interaction with a slightly different address-space allocation.) This computer interacts via an 8-line by 40-character LCD display and keyboard, uses a mass storage peripheral (3¼ in. floppy or endless-loop "wafer" tape) and generally serves as a BASIC oriented personal computer with voice I/O capability. A second 65C02 handles voice output and speech recognition tasks. A third 65C02 provides motor control.

Extensive software options allow Gemini to work without having to learn BASIC or

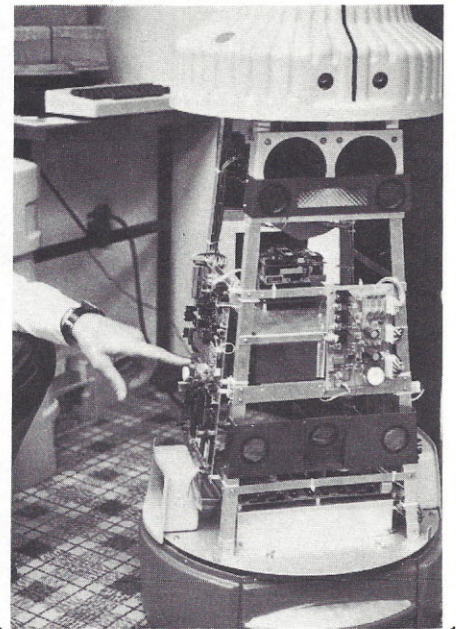
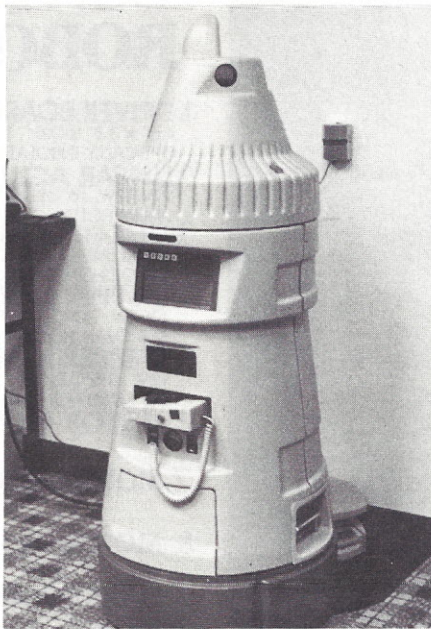
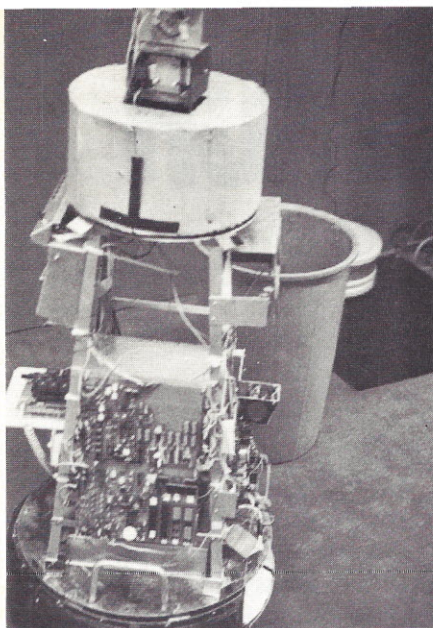
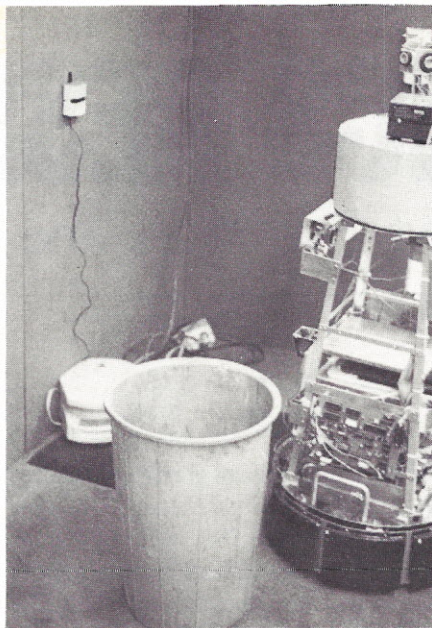


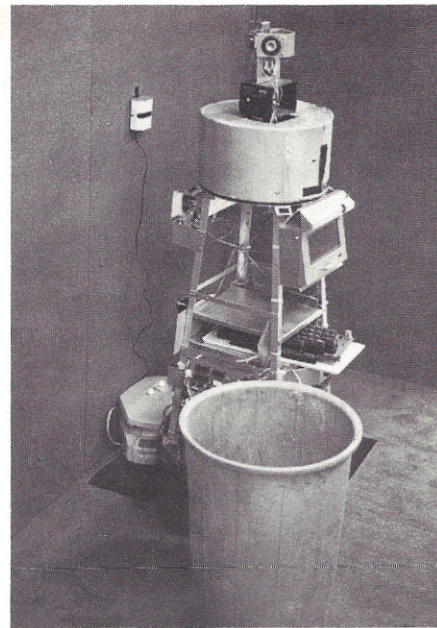
Photo 1: Two views of the Gemini autonomous robot, with clothes on (a) and naked (b). In 1a the robot is shown nestled up against a charging station located on a black anti-static pad below a wall-mounted room identification beacon. In 1b we see Gemini's innards. Note the convex battery charger connection at the bottom of the robot, designed to mate with the corresponding pair of plates on the charging station partially seen in 1a.



2a



2b



2c

Photo 2: A sequence of photos taken while an earlier development model of Gemini seeks its charging station in a demonstration room. We start at (a) where the robot sees the charger station wall beacon but senses an obstacle in the way of a direct path. In our demonstration, the robot tested and probed for a while. After a couple of false starts, it finally moved to a position where it found a direct path, as shown in (b). The end result of the demonstration was to move forward into its charger, activating the charging process as signified by the two lights turned on.

assembly language programming. This software includes a Scheduler package to orchestrate periodic and random behaviors of the beast using its real-time clock. This is probably the single most practical application feature of Gemini—a robot that

remembers and reminds. But for those of us with programming experimentation proclivities, Gemini adds a new dimension to the possible enjoyment of this craft: real time and motion control.

Motion control and navigation software

of Gemini allowed us to watch a naked prototype seek out its charging station in the presence of a wastebasket obstacle. The station (Photos 2a to 2c) is the object on the floor of the demonstration room under the "Room #1" beacon transmitter which we see mounted on the wall.) In Photo 2a, Gemini can see the beacon and begins approaching it to sip the electric juice of its life. As it cruises forward Gemini senses the wastebasket obstacle. This causes it to ponder about alternative methods of reaching its beacon goal. As we see in Photo 2b, a decision has been made to go around to the right, where a direct path to the beacon and charger is possible. Executing the direct path, the proto-Gemini is seen happily imbibing at its electronic food trough in Photo 2c. The behavior is incredible to watch.

Our observations of Gemini were presented in the environment of the research laboratories in which it was designed. Based on what we observed of Gemini's substance, engineering and behavior, we can hardly wait to get our hands on a production version. Then we'll do the ultimate test—is Gemini's behavior reproducible in the real world away from its birthplace? More on this later. ■

GEMINI SPECIFICATIONS

Each of Gemini's main functions is controlled by a separate Rockwell 65C02 CMOS microprocessor. The peripheral computers communicate with the central processor over serial communications lines. The central processor can save power by determining when the peripheral computers are turned on and off.

The central computer has 64 Kbytes of read-only memory and 56 Kbytes of programmable memory plus communications capabilities to all other processors.

The voice input/output and sound computer has 24 Kbytes of read-only memory and 16 Kbytes of programmable memory. The voice and sound generators are separated so Gemini can speak and make music at the same time. This board also handles the voice recognition routines for storing commands from up to three users.

The propulsion control computer controls all movements and coordinates the ultrasonic position sensing arrays. An optional fourth, remote computer is available that allows Gemini to control BSR controllers, modems, and other external devices over a radio control line.

Standard sensors include light, sound, temperature and battery voltage. Sensors for barometric pressure and smoke are optional. Gemini also comes with nine ultrasonic collision avoidance and navigation sensors that help it move from room to room. Other standard hardware includes a real-time clock, 16 channel, eight-bit CMOS analog to digital converter, an RS-232 serial communications port, a Centronics printer port, a hardware random number generator, a joystick controller, and a charger. Gemini's hardware can be increased through the use of the four peripheral expansion ports based on the Apple II/II+ expansion bus.

Gemini is equipped with its own cordless, detachable keyboard and a 40-character by 8-line alphanumeric liquid crystal display.

The software includes a 90 Kbyte "artificial intelligence" operating system, automatic self-checking and diagnostics on power up, extensive demo programs, a task scheduler program, and a voice synthesizer with text-to-speech software.

Optional software includes a three-user, 256-word voice recognition system with adaptive learning ability, an integrated voice command language (VOCOL), a user-configurable security guard program, and a floating-point BASIC with robot control commands.

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ROBOTICS RESEARCH

The Next Five Years and Beyond

Arthur Coleman
Human Input
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The technologies upon which robots depend are changing rapidly. New materials, motors, sensors, and software promise improved robot performance over the next five years. What trends will have the greatest impact? What technologies will succeed? These were just a few of the questions facing the 150 research scientists who attended the *First World Conference on Robotics Research*.

The conference, entitled *Robotics Research: The Next Five Years and Beyond*, was the brainchild of Roger Nagle and Robotics International of the Society of Manufacturing Engineers. According to Jim Slaughter, one of the conference organizers, "We looked around and saw a need for an open forum for the diverse research activities occurring around the world. We felt a conference such as this would provide an opportunity for the open exchange of information and ideas."

In that sense, the conference was highly successful. The 29 papers presented covered almost every aspect of robot design. Visitors to Lehigh University, where the conference was held, had the opportunity to visit the laboratories of the new Institute for Robotics Research. These labs featured miniature assembly lines constructed with Microbot and Rhino robots as well as a new CAD/CAM facility. Free exchange workshops ran concurrently with the lab tours on subjects including mobile/autonomous robots and high-precision robotics.

GENERAL ISSUES

The conference's general themes were similar to those discussed at Robots 8, although they were approached from a more theoretical perspective. The need for better modeling and control of dynamic responses was expressed throughout the conference sessions. This emphasis reflects

the increasing amount of research that has been dedicated to developing dynamic laboratory models. The lack of accurate, computationally efficient control software has limited the expansion of robots into higher-precision applications. It has also hindered the development of flexible end effectors and the development of applications involving multiple arms.

A second recurring topic, clearly associated with the control issue, was the need for better sensor technologies. While better sensor design was important, the more important issue seemed to be how to integrate sensory data into control models. According to Dr. Nagle, "The control technology needed to evaluate sensory data, provide coordinated motion, and avoid collision, is beyond the state of the art."

A third recurring topic was the need for robot software and hardware standards. The slow development of control software was partially attributed to: a lack of standards for interfacing sensors with software packages, a lack of an industry-standard robot control language, and a lack of standards for attaching end effectors to the robot arm.

The last recurring topic of conversation, mainly among robot users, was the need for robots and software designed to solve specific problems. "People are trying to adapt spray painting robots to other applications, and it just doesn't work," says Dr. Barry Weissman of AT&T's Engineering Research Center in Princeton, New Jersey. Dr. Weissman's comment reflected a general frustration at the lack of robot systems designed to meet specific real-world problems. There was a shared concern among potential purchasers that robot manufacturers were not interested in performing development work and that, in many cases, they lacked the experience to do so.

CONTROL THEORY AND KINEMATICS

Three conference sessions were dedicated to kinematics and control theory. While the presentations covered a wide range of topics and suggested progress in developing control models, control software seems to require more work before robot performance can be pushed past its present limits. The major limitation continues to be developing a model that is both robust and computationally efficient. One symptom of this is the fact that most of the models presented had been implemented only as simulations, and had yet to be tested with actual robot manipulators.

The papers on control theory covered both path planning and path tracking. Under the path tracking heading, Claude Samson, from IRISA in France, presented a paper on a nonlinear control algorithm for a robot manipulator. The superiority of the proposed nonlinear control is that the feedback gain used by the system increases only when the effects of modeling errors are significant. Otherwise, the feedback gain remains relatively small, thus reducing the system's sensitivity to measurement noise. The drawback to such nonlinear controls has been their computational burden. However, by assuming the robot arm has a diagonal inertia matrix and a center of inertia located on the principle axis of symmetry, Samson claims he is able to reduce the computational burden by a factor of three with minimal loss of accuracy.

Mark Spong, from Cornell University and chair of the session on control theory, also presented a nonlinear control scheme. Spong's approach differed from Samson's in that it used a pointwise optimal control scheme (also termed *optimal decision strategy*) to follow a trajectory. Spong reported that at present, the observed overshoot and undershoot allowed by the model were "unacceptable for robotics ap-

plications." However, ongoing research is expected to resolve the limitations presently found in the model.

Bruce Krogh's paper on path planning presented an alternative to more traditional methods of planning trajectories. Path planning has traditionally required a world model of a robot's environment and a complicated series of algorithms for calculating the best open path through a series of obstacles. The problem with these more traditional methods is that they assume prior knowledge of the entire workspace which, in reality, cannot always be known in advance. They are also computationally complex and produce poor dynamic trajectories.

The methodology presented by Krogh, termed the *potential field approach*, removes these limitations. This methodology for guiding a robot through an environment involves two basic types of objects: a goal and obstacles. Both the goals and obstacles have potential fields associated with them, much as a magnet has an associated magnetic field. The strength and direction of the obstacles are represented by *avoidance vectors*, while the strength and direction of the goal is represented by an *attraction vector*. The sum of these vectors creates an acceleration vector for the robot to follow. An example vector diagram is shown in Figure 1.

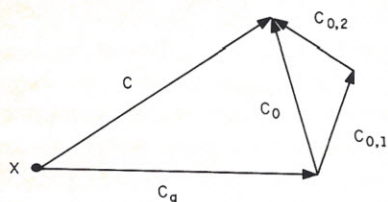


Figure 1. Bruce Krogh's method for path planning. The goal exerts an attraction force represented by the attraction vector c_g . Obstacles in the path are represented by avoidance vectors $c_{0,1}$ and $c_{0,2}$. The summation of the two avoidance vectors is represented by c_0 . The vector representing the motion required to go from point x to the goal is the sum of the avoidance vector and the attraction vector. This acceleration direction is represented by c .

The vector is recalculated at each instant, thus allowing the robot to adapt to changes in its environment. Krogh claims that this method reduces the computational burden associated with path planning, while improving the dynamic trajectory over more traditional methods. Such a potential field algorithm was originally developed by Dussamad Khatib about five years ago. A system based on such an algo-

rithm is currently being developed at Rockwell International in California. Paul Gryzbowski, the system designer, concurs with Krogh's assessment. "The advantage of this theory is that it significantly reduces the amount of programming we have to do."

The papers on kinematics and dynamics covered a wide range of topics. Presentations included a paper on learning algorithms by Richard Gawronski of the University of West Florida, and a paper by J. Barhen and S. M. Babcock on parallel algorithms for calculating robot dynamics. Jay Mendelson, now with IBM, described the use of new compliant materials and suspensions to improve the dynamic response of a robot arm. Mendelson, while a graduate student at Carnegie-Mellon, analyzed aluminum covered with a 0.125 in. layer of vinyl as a compliant material for use in robot arms. He found that because the two materials have different ranges of damping frequencies, they provide a material which is sturdy yet filters dynamic disturbances. Mendelson's second project involved designing a compliant

suspension system for a robot arm. The system (Figure 2) involved two concentric metal beams connected by conventional rubber vibration isolation springs. Although the arm was never actually built and tested, the transmittivities were calculated (Figure 3) and yielded excellent results.

SENSORS

Sensor presentations concentrated mainly on tactile and vision systems. Tactile sensor researchers presented papers on both polyvinylidene flouride (PVDF)-based (piezoelectric) and silicon-based (capacitive) sensors. While the research on both types of sensors is still in its initial stages, it appears that the development of Kynar film has provided a great deal of impetus to the development of piezoelectric sensors.

The advantage of the silicon-based sensor approach is that it increases the pressure sensitivity of the sensor over the more traditional conductive elastomers,

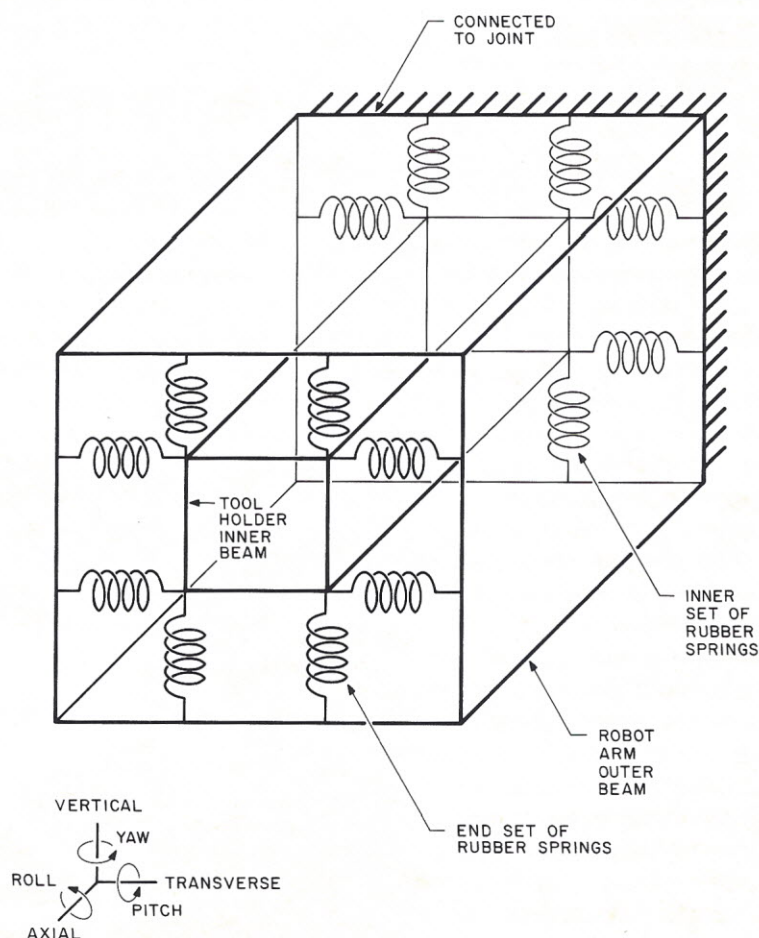


Figure 2. Mendelson's compliant suspension system for a robot arm. The interior beam is suspended by conventional rubber vibration isolation springs.

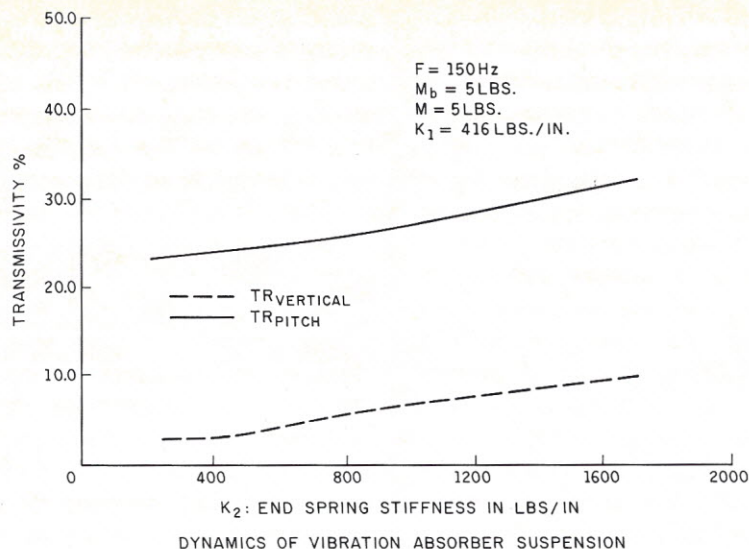


Figure 3. Predicted transmissivity of a robot arm suspension system.

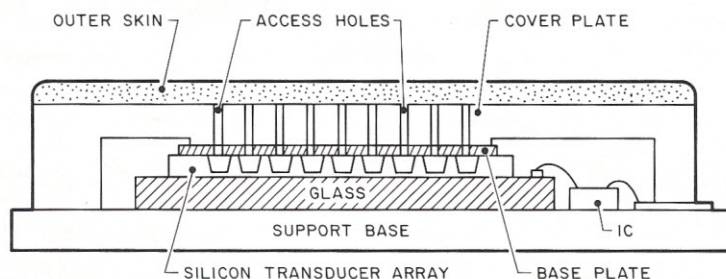


Figure 4. A tactile sensor with a 16 by 16 array of capacitive cells with 1 mm spacing.

while minimizing the influence of thermal effects on performance. Dr. K.D. Wise from the University of Michigan presented a series of such sensors (Figure 4). The largest *tactile imager* involved a 16 by 16 array of capacitive cells with a 1 mm spacing. The basic capacitive cell consists of a selectively etched silicon diaphragm (which moves in response to applied pressure or force) and an opposing glass substrate. The silicon substrate is hermetically bonded to the glass using an electrostatic seal. A perforated cover plate sits above the array of cells to protect them. The entire unit is covered with a pliable and replaceable pad which acts as the outer skin of the sensor. The deflection of the diaphragm due to an applied pressure or force creates a change in capacitance which is detected by the sensor's readout circuitry. Dr. Wise reported resolutions of 1 femtofarad (fF), although he did note that noise, leakage, and temperature drift were still affecting the performance of the sensor.

Two papers were presented on piezoelectric sensors, both based on PVDF films. Piezoelectricity—*pressure electricity*—is the capability of crystalline materials to change their dimensions when subjected to an electric field or, conversely, to produce electric signals when mechanically deformed. While PVDF is not the only

piezoelectric material, it has several advantages over piezoelectric ceramics like lead zirconate titanate (PZT). PVDF can be subjected to electrical fields 100 times greater than those applied to PZT before either depoling or material breakdown occurs. More important, PVDF is a far better transformer of mechanical to electrical energy. It also has the advantages of being lightweight, flexible, and can operate over a wide range of temperatures. Its major weakness is its susceptibility to low-frequency electromagnetic interference (emi) sources, such as 60-cycle fluorescent light fixtures, and to high-frequency interference. Thus, PVDF must typically be shielded with conductive paint or foil.

The most advanced use of PVDF was reported by Dr. D. de Rossi and P. Dario of the University of Pisa (Figure 5). Drs. de Rossi and Dario have developed an integrated tactile and visual imaging system involving three types of scanners:

- a piezoelectric and pyroelectric base on which objects rest. The base consists of an 8 by 16 array of PVDF sensing elements, 1.5 mm in diameter, with a center-to-center spacing of 3.2 mm. The base provides a low-resolution pseudo-vision for two-dimensional object detection.
- an ultrasonic range sensor to sense the manipulator's proximity to an object on the base.
- a tactile sensor that mimics the sensory features of human fingertip skin. This sensor consists of two layers of PVDF separated by a nonconducting layer of rubber.

While the base sensors identify the object, the ultrasonic sensors allow the manipulator to move quickly and accurately.

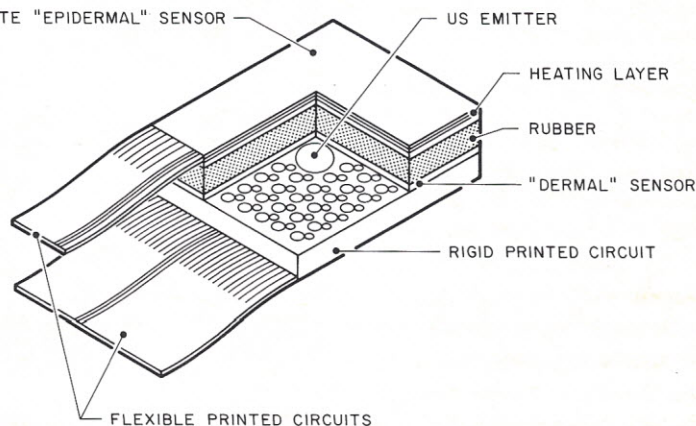


Figure 5. A multilayered, anthropomorphic tactile transducer.

ly to its proper position without colliding with other objects in the workspace. The tactile sensor in the gripper provides feedback to the manipulator to ensure the object is handled properly.

The presentations on tactile sensors provided some interesting surprises; the papers on vision systems fewer. The two systems employing vision systems in conjunction with robot arms used standard vidicon cameras and processing algorithms. Image processing was performed on simple, nonmoving objects in a highly structured environment, and yielded two-dimensional images.

Professors R.D. Schraft and K. Melchior of the Fraunhofer Institute for Production and Automation Technology described a system which inspected water pumps and water pump gaskets for positioning errors and defects in workmanship. The system presented by Alan Pugh of the University of Hull, England, used vision to inspect and select silicon pellets for use in the assembly of power diodes. Neither application involved overlapping parts and the algorithms seemed much simpler than those presented at Robots 8 by Scott Roth of Adept Technologies.

Azriel Rosenfeld, chair for the session on vision, summed up the state of the art when he said, "When you go out to buy a vision system, you generally find technology 20 years or more old." It was generally agreed by most speakers that true three-dimensional object recognition was years away. Such recognition will depend on improved software for extracting object features and recognizing textural properties associated with objects. Three-dimensional vision will also depend on improvements in high-level vision capabilities—the ability to interpret the image and identify the object from its specific features. "While there is much activity," according to Dr. Nagle, "it is difficult to predict specific results [in vision research]."

MOBILE ROBOTS

One of the most actively researched fields appeared to be mobile and autonomous robots. A wide range of systems was presented at the conference including:

- a Navy reconnaissance robot, driven by two Mark IV torpedoes
- a French robot (From Nomed Corp.) for scrubbing barnacles from the sides of ships

- a pool-cleaning robot named Dolphin
 - a dual-manipulator robot for inspecting wires and pipes in particle accelerators and nuclear power plants.
- Of equal interest was the theoretical discussion of design principles for mobile robots. A distinction was drawn between mobile robots and mobile *autonomous* robots. RIA defines a mobile robot as a robot mounted on a moveable platform. A mobile autonomous robot, however, is a "robot acting independently and of its own volition." According to Harvey Mierian of PhD Technologies these two issues are often confused. "How much and what type of mobility you give your robot is a separate issue from how much decision-making capability it has." Dr. E. Kafritsen, who is also working on a mobile robot for nuclear applications, agreed. "Many mobile robots, particularly those working in well-defined environments and performing well-defined tasks, do not need a great deal of autonomy. Other issues, such as retrievability, reliability, and safety become more important."

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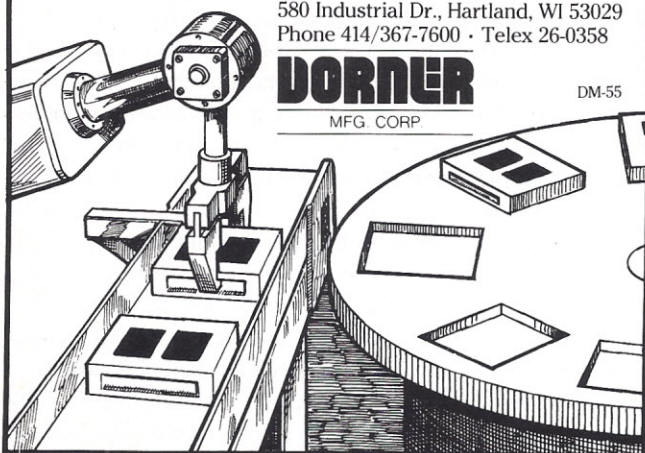
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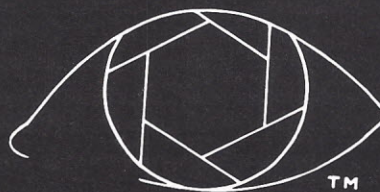
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plications such as microsurgery and semiconductor packaging was discussed at some length. High-precision applications are those which require accuracies and repeatabilities of less than 1 micron. Until now, even conceiving of robots with such accuracies was out of the question. But with the advent of new motors and improved control software, using robots for these applications may become a reality in the next five years.

It was clear from the discussions headed by Susan Sachs of AT&T's Engineering Research Center, that many design issues need to be resolved before robots could be applied in such micromanipulations. One key concern is the effect of subtle physical changes that are unimportant in today's robots but which may have more noticeable effects in applications requiring 1 micron accuracy. "For example," says Dr. Sachs, "as the arm and its motors operate, they will generate heat. Differential expansion of the metal due to heating may impair the accuracy of the gripper. Thus, a vision system would be necessary just to ensure that we know the gripper's exact position."

A second issue is the type of payloads robots would be required to carry for these applications. Since there is a significant tradeoff between payload and accuracy, a well-defined payload range is required to ensure 1 micron accuracy.

MODULARITY

Another recurring topic of the conference was the issue of modularity. Modularity has several aspects. First, it refers to the robot's ability to interchange various pieces of hardware—end effectors and sensors in particular—without remachining or rewiring. Second, modularity refers to the ability to design software in building block fashion, so that various routines and protocols for robot control can be added or changed without interfering with other elements of the robot's programming. Third, modularity implies interchangeability of parts and software between different robots so that design and development efforts can be shared by a larger number of research groups. Modularity is an important issue because it would shorten the time and lower the costs associated with developing new robot systems. The problem, however, "is a complete and total lack of standards, both for software and hardware interfaces."

Little work has been done to develop standards, although the National Bureau of Standards may soon be organizing workshops on the issue. The major reason for this state of affairs has been the lack of support provided by major robot manufacturers. Robot producers prefer to ensure the survival of their installed bases by locking users into proprietary systems, even though robots must ultimately, like computers, become linked via standard operating systems.

Several papers dealt with various aspects of standards. Robert Thornhill, Martin Marietta's representative on the CAM-I project in Arlington, Texas, presented a paper on the development of an off-line programming system for a robotic workcell. The system, called the *robot planner*, appears similar to McAuto's new off-line simulation software packages PLACE, BUILD, COMMAND, and ADJUST.

A hardware-oriented paper presented by John Vranish of the National Bureau of Standards discussed a modular *quick change* wrist which allows a robot to quickly exchange one end effector for another without operator intervention. The wrist, which can handle a payload of up to 50 lbs., consists of two plates (Photo 1). The A plate (on the left) contains the locking

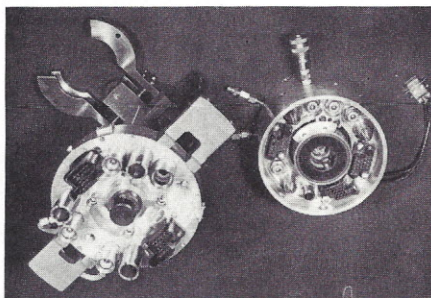


Photo 1. A working model of the National Bureau of Standards' modular robot wrist.

mechanism and acts as a manifold for six dual-purpose hydraulic/pneumatic lines which are dispersed around the circumference of the plate. The lines are used for powering the various tools which may be part of the end effectors. The B plate holds the taper for the locking mechanism, and is attached to the end effector. A total of 38 electrical channels with frequencies from DC to 2 MHz pass between the two plates. A series of holsters sit in the waist of the robot and hold the various end effectors when they are not being used.

Designing a quick-change wrist is not simple; several unique design problems must be addressed. First, the wrist must

include sensors to verify that the locking mechanism has opened or closed on command. Otherwise the end effector could potentially fly from the workspace and damage equipment, or more significantly, injure a human operator. For the same reason, mechanisms must exist that ensure that the end effector remains firmly locked in place if the electrical or pneumatic power is interrupted. The locking and unlocking mechanism must also be able to withstand hydraulic back pressure from the hydraulic lines. A constraint in resolving this problem, however, is that the wrist must be small, lightweight, and operate at pneumatic pressures of 90 psi, which is the standard pressure in pneumatic lines for shop tools.

A second problem is plate alignment. Each plate must be aligned exactly for six degrees of freedom so that the mating connectors will insert smoothly. Dr. Vranish partly solved this problem by using a vision system and a series of locking pins which align the plates as they move together.

A similar problem is encountered when attempting to place the end effector in its holster. The problem is complicated by the fact that a hydraulic robot has little compliance when its wrist is held close to its waist. In this case, the problem was solved by angling the outer surface of the holsters and by engineering "ears" onto the B plate to mate with catches in each holster to offset the arm's limited movements near its waist.

STUDENT PROJECTS

Conference attendees had a chance to explore several student projects at the Lehigh Robotics Lab. One project arranged several Rhino and Microbot robots as a workcell to assemble a smoke alarm. The workpieces were transported from each workstation by a miniature conveyor system. According to Robert Fletcher, one of the system's designers, the robot activity is not coordinated by a master controller. Rather, each robot communicates directly only with those devices with which it must synchronize. This approach simplifies both design and reprogramming.

Michael Chang, a graduate student in Industrial Engineering, designed a system for performing bin-picking applications. The system consisted of a Puma 650 arm connected to a vidicon camera designed at the University of Rhode Island. The camera

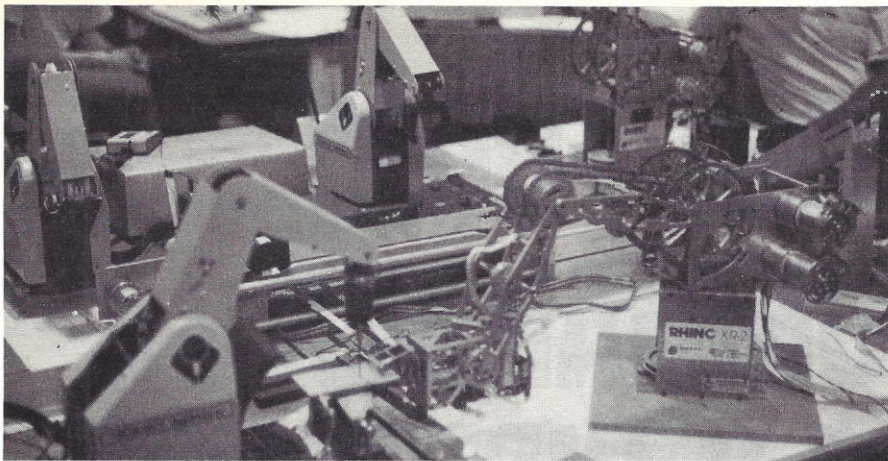


Photo 2. A manufacturing workcell composed of Rhino and Microbot manipulators at the Lehigh University Robot Lab.

produced two-dimensional images of 320 by 240 pixels with 64 gray levels. Since the vision system could only produce two-dimensional images and since objects in a bin needed to be distinguished in three dimensions (if they overlap or are stacked), another sensor system was required to provide resolution in the *z* direction. Chang installed an LED optical sensor on the gripper to provide resolution in this third dimension.

Keith Werkman, a graduate student in Computer Science, displayed a robot con-

trol language he had developed for a Rhino robot. The language is programmed in assembler, has 126 instructions, runs on an IBM PC, and uses 34 Kbytes of memory.

CONCLUSION

Overall, SME's first world conference on robotics research provided an excellent overview of the technical problems that will confront the robotics community in the next five years.

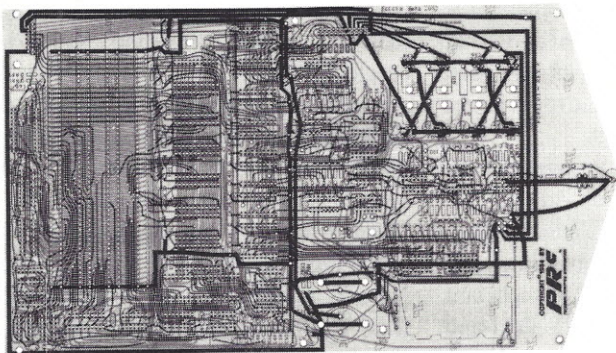
At the same time, it suggested that many of the major issues of immediate concern—the desire to improve dynamic modeling and response, the need for more general-purpose sensors, as well as the development of industry standards, and a broader base of applications—are receiving significant attention from the research community. A recent study by the U.S. Office of Technology Assessment predicted that many of these issues can be resolved by 1995. The conferees at *Robotics Research, the Next Five Years and Beyond*, certainly seemed optimistic that such predictions could be fulfilled.

The next conference is scheduled for summer 1986, and may be held in either a university or industrial setting.

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REPORT FROM THE UNMANNED VEHICLES CONFERENCE

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The Association for Unmanned Vehicle Systems held its 14th annual meeting last August in Washington, D.C. Although an unmanned vehicle is surely a robot, hardly anyone in the Association uses that word, preferring such phrases as *tactical autonomous weapons systems*. The reason is that most members come from the world of military vehicles where robotics has only recently proven itself, and where manned vehicles continue to set the standards.

Airborne RPVs (remotely piloted vehicles) are the centerpiece of the Association. The most advanced RPV is Lockheed's Aquila. It's also the best looking—a stingray with flat black paint, very futuristic and menacing. Other American competitors, such as Boeing's Pave-Tiger, have the contours of a standard missile or jet airplane. The Israeli RPV (made by Tadiran) is less dazzling. In fact, it looks like a World War II cargo plane. (However, the Israeli's are quick to point out that theirs is the only battle-tested RPV.)

Despite the visual interest and obvious potential of RPVs, the big contracts have not yet arrived. According to RPV enthusiasts, one reason for the lull is the "white scarf" mentality. RPVs appear to threaten fighter pilots and tank commanders, the "glamour" roles that play an important part in the military reward system. Of course, those who wear white scarves explain their reluctance different-

ly. An Air Force general and former fighter pilot made a presentation critical of RPVs. He concluded that drones didn't work very well in Viet Nam, and that the losses cost much more (per sortie) than losses from manned sorties. Everyone admitted that drones were poorly engineered at the time, but a questioner reminded the general that no pilots were killed or captured as a result of drone use. Also, since drones were used to draw enemy fire, many drone losses could be counted as gains.

Lockheed (Austin, TX) answers the engineering challenge with its Aquila. The Aquila has flexibility, which pleases military buyers who can't say for sure how and where RPVs will be used. An important mission will be to circle a battlefield and send out a jamming signal. The Aquila itself is almost invisible to radar. It can travel at speeds up to 130 mph and climb to 10,000 ft. although it normally flies at 2,000 ft. Aquila can send back detailed video and other surveillance data, and can use lasers to tag ground targets. Lockheed representatives claim that the Israeli RPV would be useless in an electronic warfare (EW) environment, while the Aquila is a formidable weapon there.

Lockheed representatives bristle when criticized for the high cost of the Aquila. They say that three-fourths of the cost can be attributed to navigation and other fancy electronics that Lockheed did not build or even recommend. But they don't go on to mention the problem of ground support.

Apparently, large crews are needed to work nets that catch the incoming aircraft.

Although various military branches such as the Marines have been issued the Aquila, they are quietly investigating alternatives. The Marines have been testing Israeli RPVs, but only one of seven drones is now operational. They are also trying a radical approach, building their own bargain-basement drone. If the Marines send out hundreds of inexpensive drones during a battle, the enemy can't afford to shoot them all down, and Marines don't have to retrieve those that survive.

The Johns Hopkins Advanced Physics Lab (Laurel, MD), under contract to the Marines, is attempting to integrate off-the-shelf equipment and spend well under \$5,000 per drone. The shelf is surprisingly full. They began with military target airplanes and loaded them with hobby aircraft equipment. They are even evaluating hobbyist computers and control software. The Coast Guard and border police are also watching this project, since they could expand their surveillance at tremendous cost savings.

Northrup, in its display, showed a mythical *march of progress* away from hobby aircraft in the late '40s toward Northrup's current design. In reality, small systems and large systems are proceeding in parallel, with much of the innovation coming at the small end. For example, the Robotics R&D Lab at the Navy Surface Weapons Command (Washington, D.C.) exhibited two

homebrew robots built by Commander Bart Everett. His robots are used as test benches in a variety of projects.

The organizers also invited Virtual Devices of Bethesda, MD, (for which I am the marketing and sales executive) to exhibit their remote control system for the HERO I robot. Virtual Devices also announced a general-purpose version of their controller. At first, not too many people visited the booth, thinking the HERO was only a toy. By the end of the conference, however, more than a few companies were setting up appointments with VDI engineers. An expert in underwater robotics said that VDI software did "ten times more" than the best packages available in his field.

Underwater and land-based vehicles gained new prominence at this year's conference. Underwater applications, such as inspecting welds on offshore oil rigs, cry out for robotic solutions. A diver's round trip can take five hours, with only three minutes of that time spent inspecting welds. A typical rig has 27 miles of welds, which means permanent duty for divers.

The problems are even more acute in arctic conditions.

The land-based Prowler from Robot Defense Systems (Thornton, CO) was also on display. The Prowler gained notoriety from a *Newsweek* article which pictured a model equipped with machine guns and camouflage paint. Officials called from various world capitals to make sure their enemies weren't buying.

The Prowler is reminiscent of a tank, and the manufacturers as well as military strategists talk about how Prowler can take a similar role. In contrast, Odex 1 from Odetics, Inc. (Anaheim, CA) doesn't look like anything but itself, a six-legged *functionoid*. In this case, observers tend to marvel at the technical beauty and forget about applications altogether. Videotapes prove that it "works" but there were no live demonstrations. Odex 1's keepers were horrified to find that the shippers had turned the robot upside down, which ruined a gyroscope and spilled the battery fluid.

The Defense Advanced Research Projects Agency (DARPA) awarded Robot

Defense Systems a development contract. DARPA, as part of its Strategic Computing Project, has also recently awarded a very large contract to Martin Marietta to develop a land vehicle that walks and converses. These are signs that unmanned vehicles are finding their niche and are shedding their image as either man-substitutes or as high-tech curiosities.

Robert Finkelstein, an official of AUVS, is promoting *Robotic Vehicle Association* as a new name that reflects this more positive identity, maintains the focus on mobile applications, and reaches out to the broader community of roboticists.

For further information, the Association for Unmanned Vehicles can be reached at 1133 15th St. NW, Washington, D.C. 20005.

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From the publishers of *Robotics Research*, the first U.S. journal of robotics science, edited by Michael Brady and Richard Paul.

A MODULAR REMOTE DATA ACQUISITION SYSTEM DESIGN

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The NSC800/Z80-based MA2000 family of Macrocomponents™ represents a unique design philosophy best described as a *soft-tech* approach to system design. Soft-tech is a sophisticated engineering solution to a generic problem: a solution packaged, presented, and supported in such a way that the user need not be exceptionally versed or proficient in a specific area of technology to develop an application. This approach to the Macrocomponent design has simplified system design, substantially reduced the design cycle, and produced a system far more flexible than other alternatives.

Developing a truly soft-tech solution to system design problems requires that both hardware and software design obstacles be minimized. The MA2000 Macrocomponent system eliminates the expense—both physical and financial—of a cooling fan, card cage, and chassis and backplane. With the exception of the MA2000 Power Supply, and some early memory modules, each Macrocomponent is packaged in 2.6 cubic inches (0.45 by 1.60 by 3.61 in.). The placement of pins on the bottom of the module, and pins on the top of the module enables the system bus to be expanded vertically and simplifies system expansion with position-independent, plug-in, application-specific modules.

All Macrocomponents are engineered to ensure simplified integration into either the Macrocomponents stacked configuration (components plugged into each other) or stand alone in an NSC800/Z80 microprocessor-based system. Extensive documentation on the components and

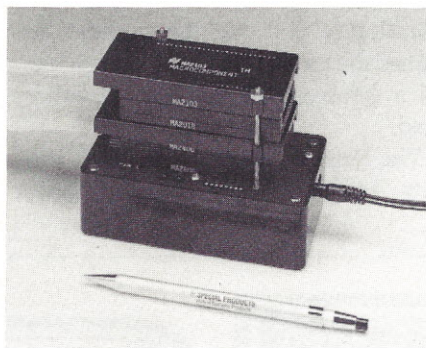


Photo 1. The MA2000 family consists of a set of small black boxes that stack on top of each other. This photo shows (from top to bottom) the MA2000 Power Supply, the MA2800 Processor Module, the MA2400 Analog Input Module, the MA2018 Static Programmable Memory Module, the MA2301 Forth Module, and the MA2103 Intelligent Communications Interface Module.

their integration into a system design is provided. A CMOS-component-based approach to Macrocomponents design, and provision for software selection of non-CMOS components, virtually eliminates power dissipation problems, and relegates the concern for system power consumption to an almost insignificant level.

The result of this soft-tech approach is a design and integration process that allows direct implementation of the final application configuration by merely plugging together the Macrocomponents that represent the blocks of a block diagram design. Since each Macrocomponent represents one specific system function (output, input, communication, etc.), each application design is custom-tailored and precisely expandable. The hardware for a fully functional Macrocomponent system

can typically be designed and implemented in minutes.

Also, since the MA2800 processor unit has a resident monitor program, the system is immediately available for software development. The physical and electrical attributes of the MA2000-family system help make it the only portable, host/target development system currently available. Indeed, with the proper portable terminal and sufficient battery power, a Macrocomponent-based development system is as portable as many of the current portable personal computers.

THE MA2000 FAMILY

There are currently seven MA2000-family members that can occupy any position on the stack and two components that must occupy the top positions. Before the inception of the soft-tech concept, the MA2016 Static Programmable Memory module and the MA2017L Static Programmable Memory module with lithium battery back-up were designed. These two modules may be placed anywhere in the stack with respect to each other, but must occupy the top of a Macrocomponent stack since they are slightly smaller than the other Macrocomponents and do not vertically extend the entire Macrobus™.

The seven Macrocomponents that extend the entire bus up the stack are the MA2000 Base Plane and Power Supply, the MA2018 Static Programmable Memory (16 Kbytes), MA2103 Intelligent Communications Interface (a Bell 103-compatible modem with intelligence), MA2232 RS-232 Serial Communications

module, MA2301 Forth Development System, MA2400 Analog Input module, MA2732 UVPROM/Programmable Memory module, and the MA2800 Processor Module (NSC800-based). A brief introduction and description of each of the seven full-bus modules follows.

MA2000. The MA2000 Base Plane and Power Supply module provides regulated +5 V (at 500 mA) and ± 12 V (at 80 mA) supplies from a pair of high-efficiency switching regulators, as well as battery back-up for system memory. Input voltage requirements are 8 to 15 VAC or 9 to 18 VDC. Either AC or DC may be applied through the power adaptor jack where it is then passed through a rectifier and input filter capacitor. System efficiency may be improved in DC powered applications by providing power through the extended system bus connector available from a 60-pin edge connector that exits from the side of the MA2000 package. An LED provides system status indication. A hardware jumper field allows interrupts to be generated from system power fail and zero-crossing for the respective purposes of system crash warning and "real-time" clock applications. The MA2000 provides the base plane and full Macrobus socket for MA2000 component insertion.

MA2018. The MA2018 Static Programmable Memory module provides 16 Kbytes of CMOS memory. The MA2018 requires only a single 5 V power supply, does not require refresh, retains data down to 2 V, has buffered outputs, has TTL-compatible inputs and outputs, and provides internal address decoding for hardware-jumpered, user-determined addresses. The maximum allowable memory in the Macrocomponent stacked configuration is 64 Kbytes.

MA2103. The MA2103 Intelligent Communications Interface is a Bell 103-compatible, full-duplex modem. The intelligence is provided by a National Semiconductor Control Oriented Processor (COPS™), the COP424C. This COPS processor functions as UART and controller, routing data to and from the CMOS 300-baud modem, the 74HC943. The module recognizes ten commands fundamental to elemental, modem-type operation as well as ten *convenience* commands that may be used to augment communication capabilities or to adapt the MA2103 to unusual data communication environments.

Communication status is available in a frequently updated register where it may be sampled by the host processor. The MA2103 is designed to occupy any location from hexadecimal 00 to FF in the I/O map. A Data Access Arrangement (DAA) circuit, integrated RJ-11 connector, flush-mounted LEDs to indicate carrier-detect and off-hook conditions, and a 2 Kbyte Electrically Erasable Programmable Read Only Memory (EEPROM) are included. The EEPROM may be programmed while in the package, although it comes with a resident Forth-coded, menu-driven program. Since only the EEPROM is not CMOS, it may be software or hardware disabled to conserve power. The 2 Kbytes of internal EEPROM may be jumper-located anywhere in the hexadecimal 0000 to FFFF memory map. Multiple units may be incorporated into the system.

MA2232. The MA2232 Serial Interface module is a complete serial, asynchronous communications system. The MA2232 may be operated in the interrupt mode with five interrupt options selectable from a hardware jumper field. The receiver-driver translates the internal UART outputs to RS-232 Standard ± 12 V outputs and acceptable UART input levels, and is the only non-CMOS system component. Data transfer rates are software-programmable and range from 50 to 19.2k bps. Full- or half-duplex operation is possible, as is software selection of word length (5 to 8 bits), parity inhibit or even/odd parity, and number of stop bits (1, 1.5, or 2). The MA2232 may reside in the I/O map at locations from hexadecimal 00 to F0 at x0 and x8 in increments of hexadecimal 10 (i.e. 00, 08, 10, 18, etc).

MA2301. The MA2301 Forth Development System is a Forth-79 Standard system consisting of the required set of nucleus, interpreter, compiler, and device words. It also includes a number of unique and powerful utilities for applications software development. These utilities include the following enhancements of the Standard vocabulary: functions facilitating system entry and timing, in-memory editing screens, a full-screen editor, an 8080 assembler, data transfer (I/O), a multitasking vocabulary, a Forth disassembler, and a method of application code reduction called DISTILL.

While some of the MA-Forth enhancements are convenience functions dictated

by the soft-tech approach of the MA2000-family philosophy, the remainder are necessities for a ROM-based development system. The ability to edit program screens in memory allows the experienced Forth programmer to code in a familiar medium with the added advantage that in-memory editing is impressively quicker than disk-based editing systems. The MA-Forth Editor is similar to that described in Leo Brodie's book *Starting Forth*.

Although Forth is faster than other structured, high-level languages, there is still the occasional need to write a section of very rapid, time-critical code. The Forth Development System provides an 8080 Assembler for machine-language coding. Also, the Forth disassembler is an extremely useful tool for program development and debugging.

The most useful tool in the MA-Forth repertoire is the DISTILL function. This function distills, or compacts, a completed Forth application program into its fundamental elements. DISTILL eliminates large blocks of the MA-Forth vocabulary—such as the assembler and the screen editor—and MA-Forth words that are application-superfluous. The remaining Forth code is reduced to its rudimentary elements (jumps, addresses, and machine code) to ensure that the final application program is as lean as possible. The MA2301 Forth Development System obviates the necessity of a disk drive for program development.

The MA2301 Forth module consists of the same standard packaging as the other MA2000-family members. Its internal hardware consists of 16 Kbytes of CMOS UVPROM and the appropriate decoding logic and output buffers.

MA2400. The MA2400 Analog Input module provides 14 single-ended, multiplexed inputs. The internal circuitry consists of a 12-bit CMOS analog-to-digital converter (the ADC1210), a software-selected heater and a superior reference, as well as a UVPROM containing convenience software. A 26-pin end connector allows access to the reference ground and voltage. The 2 Kbytes of UVPROM in the MA2400 may be situated anywhere in the memory map from hexadecimal 0000 to FFFF and anywhere from hexadecimal 00 to FF in the I/O map.

MA2732. The MA2732 UVPROM/Programmable Memory Socket module con-

sists of the decoding and buffering circuitry in an MA2000-compatible package to allow custom memory configurations. Either read-only or programmable memory can be plugged into this module in various combinations. PROM capacities of 2 Kbytes, 4 Kbytes, and 8 Kbytes are possible. Read-only/programmable combinations of up to 4 Kbytes of read-only memory in the first socket and an additional 2 Kbytes of programmable memory in the second socket may be assembled.

MA2800. The MA2800 is an 8-bit, CMOS microcomputer system composed of processor, 4 Kbytes of read-only memory, 2 Kbytes of programmable memory, parallel and serial I/O ports, a system clock, programmable timer, 2.5 MHz operation, and an optional real-time clock (MA2802). The central processor is an NSC800 which is 8080/Z80 software compatible. Its memory and I/O restrictions are 64 Kbytes and 256 devices respectively.

The MA2800 has an internal and external memory map. The lower 16 Kbytes of memory (hexadecimal 0000 to 3FFF) may be hardware jumpered or software selected. When selected, the external memory map

shadows the internal memory map. The upper 48 Kbytes of memory space is common to both the internal and external maps.

The 4 Kbytes of processor programmable read-only memory (PROM) is residence for the MA2800 monitor program. The monitor program is an aid to software development, and I/O device and memory manipulation. The monitor program claims 256 bytes of programmable memory for a scratchpad, releasing the remainder to user allocation. The read-only and programmable memory constitute 6 Kbytes of the 16 Kbytes of the internal memory map.

An NSC810 in the MA2800 module provides three I/O ports and a timer. Port A is eight bits and ports B and C are both six bits. Strobed-mode operation is possible using port A and three bits of port C for handshaking. Two bits of port B can be controlled by the monitor program and utilized as a software-controlled UART (a 5 V zener diode is required on the input line, anode to ground). All three ports, timer out/in, clock, oscillator in, and ground are accessible through a 26-pin connector off the end of the package.

MA-FORTH

The addition of MA-Forth in the form of the MA2301 Forth Development System was a major milestone in the MA2000 family's soft-tech philosophy. The MA2301 module provides a complete development system in one package. The addition of 48 Kbytes of programmable memory (MA2018s), a central processor (MA2800), an RS-232 communications interface driver (MA2232), a power supply (MA2000), and a dumb terminal are all that is necessary to begin program development. System hardware development merely requires plugging in system-specific modules. This development system then becomes both host and target. The implication is that, since Forth encourages modular program development and is a highly interactive language, code may be tested in modular form as rapidly as it is developed. This is the ideal development environment.

Forth code is exceptionally efficient. This efficiency results in a coding that is already concise and compact. In addition to this inherent economy, the DISTILL function enables the further reduction of Forth application code. Many control applications can be DISTILLED to occupy less than 4

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Kbytes. In situations such as this, inexpensive arrangements for customizing 4 Kbytes of MA2800 resident read-only memory are possible. Programmable memory requirements of less than 2 Kbytes can be serviced by the MA2800 internal memory. Larger applications may be implemented by the addition of MA2732s for PROM/programmable memory requirements, and MA2018s for programmable memory requirements. Also, the soon-to-be-released MA2700 Universal Memory module will allow developers to develop, DISTILL, and program any type of programmable read-only memory (UVPRM or EEPROM) right on the Macrocomponent stack.

Unlike other development systems, an MA2000-family-based system is truly portable. Its low power requirements, small size, disk drive independence, and plug-in bus allow an ease of transportability that makes the system a pleasure to work with. It is easily moved from lab to desk to any location that an adequate, low-power, laptop portable terminal with an RS-232 connector can go. Also, its ease of expansion—integrate a block of code and plug in a component—make it ideal for adaptable systems, or systems offering numerous options.

REMOTE DATA ACQUISITION SYSTEM DESIGN

An illustration of the simplicity of hardware

and software design using MA-Forth and the Macrocomponents is demonstrated here by designing a portable data acquisition system. There are many applications for compact, efficient data acquisition systems: monitoring weather conditions, hazardous environment and remote system monitoring, and security systems. A generic data acquisition system that monitors its own power, and samples, stores, and downloads data to a central system for processing will be designed.

System Hardware. The hardware requirements for this system are simple: power supply, processor, programmable memory for data storage, analog input unit, a modem (assuming the availability of a phone line), power, and transducers. This translates into an MA2000 power supply, MA2800 Central Processor, an MA2018 (16 Kbytes of Static Programmable Memory) for data storage, an MA2400 Analog Input Module, the MA2103 Intelligent Communication Interface, various applications-specific transducers, and power. We will assume access to AC power with battery back-up and leave the transducer specifications as generic functions (pressure, temperature, flow, etc.) which need only be stored and transferred as raw data in our system.

Depending on the desired development environment (Forth and monitor programs or the Forth system alone), the processor module is jumpered for internal or external memory map. The static programmable memory is jumpered for hexadecimal 4000. The MA2103 is located at hexadecimal F0 in the I/O map and the EEPROM disabled using the jumper field. The MA2400 is located at hexadecimal FC, FD, FE, and FF, and has its UVPRM also disabled by proper jumpering. Module jumpering is carefully described in the MA2000 Series Macrocomponent™ User's Guide. The software development will require the addition of the MA2301 Forth Development system jumpered at hexadecimal 0000 and two additional MA2018s jumpered at hexadecimal 8000 and C000 respectively. Once the MA2000-family modules are plugged together and jumpered, the hardware for the data acquisition system is designed and constructed. Only the software development remains.

SOFTWARE DESIGN

A remote data acquisition system need not

```

1 LIST
SCR #1
0 ( DATA ACQUISITION      GORDON COOK      8/15 84 )
1 VARIABLE AC_POWER_SAMPLE  VARIABLE POWER_FLAG
2 VARIABLE DATA_COUNT VARIABLE TEMPERATURE 288 ALLOT
3 : RESET 0 AC_POWER_SAMPLE ! 0 POWER_FLAG ! 0 DATA_COUNT !
4 TEMPERATURE 288 0 FILL ;
5 : SECONDS 0 DO 1100 MSEC LOOP ; HEX
6 : GAIN_&_CHANNEL FC P! ;
7 : START_CONVERT 60 FD P! ;
8 : DATA_OUT BEGIN FF P@ F8 AND DUP 8 AND 0 = IF DROP ELSE
9 FE P@ LEAVE THEN UNTIL ;
10 HEX : PHONE# 36 38 34 36 31 32 37 38 30 34 ;
11 : HOLD1 1FF 0 DO LOOP ; : TO_MODEM F0 P! HOLD1 ;
12 : FROM_MODEM F0 P@ HOLD1 ; : TRANSMIT 3 TO_MODEM ;
13 : DIAL_PHONE# 5 53 5E 50 E 0 DO TO_MODEM LOOP ;
14 : OFF_HOOK 55 TO_MODEM ; : HANG_UP 4 TO_MODEM ;
15 : STATUS 6 TO_MODEM ; : READ_CHAR 5 TO_MODEM ; .
OK
2 LIST
SCR #2
0 ( SCREEN 2 OF DATA ACQUISITION  GORDON COOK )
1 : SAMPLE_POWER 2 GAIN_&_CHANNEL START_CONVERT NOOP DATA_OUT ;
2 : TEST AC_POWER_SAMPLE @ 2 > ; : TIMER 599 SECONDS ;
3 : SAMPLE_TEMP 3 GAIN_&_CHANNEL START_CONVERT NOOP DATA_OUT ;
4 : STORE_SAMPLE_TEMP DATA_COUNT @ DUP >R 2 * TEMPERATURE + DUP
5 >R ! R> 1+ ! R> 1+ DATA_COUNT ! ; : FULL? 144 = ;
6 : RING_DETECT 10 0 DO FROM_MODEM 2 AND IF LEAVE THEN LOOP ;
7 : CARRIER_DETECT BEGIN STATUS 10 0 DO READ_CHAR
8 RING_DETECT FROM_MODEM 4 AND IF LEAVE THEN LOOP DIAL UNTIL ;
9 : PHONE_UP BEGIN OFF_HOOK DIAL CARRIER_DETECT UNTIL ;
10
11 : POWER_FAIL 54 55 4F 20 43 41 6 0 DO TO_MODEM LOOP ;
12 : DOWN_LOAD TRANSMIT 288 0 DO TEMPERATURE I + C@ TO_MODEM LOOP ;
13
14 : POWER_SAMPLE_POWER 3306 > IF POWER_FLAG @ 1+ ! THEN TEST ;
15
OK
3 LIST
SCR #3
0 ( SCREEN 3 OF DATA ACQUISITION      GORDON 'COOK )
1
2 : DATA_ACQUISITION
3 BEGIN TIMER RESET POWER
4 IF PHONE_UP POWER_FAIL HANG_UP 0 AC_POWER_SAMPLE !
5 ELSE SAMPLE_TEMP STORE FULL?
6 IF PHONE_UP DOWN_LOAD HANG_UP
7 THEN
8 THEN
9 UNTIL ;
10
11
12
13
14
15 DATA_ACQUISITION
OK

```

Listing 1. Forth code for the data acquisition demonstration system.

be sophisticated. A suitable system need only acquire data, transform it into the appropriate form, accumulate data in specific arrays, and transmit the accumulated data to the central system on a regular basis. Provision should also be made to flag and report incidence of a primary power outage so that primary power may be restored. A sample flowchart appears in Figure 1.

Although both manual and auto operation modes are available for the MA2103 and the MA2400, the illustration of Forth coding for the auto modes would be simple to the point of embarrassment. Therefore, the following code is structured for manual operation.

As in any Forth system, coding begins with the most fundamental blocks. Coding for arrays and variable declarations is similar to that in other systems. At this point, it is appropriate to note one of the many great strengths of Forth; self-documentation through the appropriate choice of mnemonics. This is easily seen in the three screens of Forth code (Forth is coded in 16 line by 64 character screens) that comprise the data acquisition system.

It is important to comment on Forth's use of a stack. Forth programs retrieve data

from a parameter stack. Forth also has a return stack for pointers and temporary storage. These stacks are last-in-first-out which gives Forth coding a Reverse Polish Notation (RPN) character: the data or parameters come before the function which operates on or with them. The coding is transparent. The first contiguous word in a colon definition (code which has a colon, ":", preceding it and a semicolon, ";", following it) describes its function. Once the screen has been loaded, the entire function described by the colon definition is available at any point in the application.

As can be seen from the code for this simple application, the first screen sets up basic variable, array, and communications code. The second screen combines words from the first screen, in modular fashion, to build complex functions. These complex functions are then invoked by other even more complex functions. The final code consists of seven lines of screen 3 which are functionally self-descriptive. The last word in screen 3 invokes the entire data acquisition function.

An illustration of Forth's modularity, flexibility, and extensibility would be to provide more sampling capability for this

system. At this point, we sample the power and temperature (SAMPLE_POWER and SAMPLE_TEMP respectively). We could easily implement a 14-channel acquisition system by merely defining a word, SAMPLE, as follows:

```
: SAMPLE GAIN_&_CHANNEL
START_CONVERT NOOP DATA_OUT ;

A loop would then perform 13 of our 14
samplings (we would redefine SAMPLE_
POWER as : SAMPLE_POWER 2 SAMPLE ;).
Remember that we are in hexadecimal, and
10H equal 16D.

: A/D 10 3 DO I SAMPLE LOOP ;
```

We would then store blocks of data, and will also require an additional MA2018 on the final application stack. Keep in mind that the word A/D does not now change the gain of the Analog Input Unit, and that such a provision may be necessary in any real application.

Once the coding is finished, the DISTILL function is used to remove the unnecessary code and the resulting program is burned into the processor PROM. The MA2301 Forth Development System and any unnecessary programmable memory is now removed and the Macrocomponent stack is ready to use.

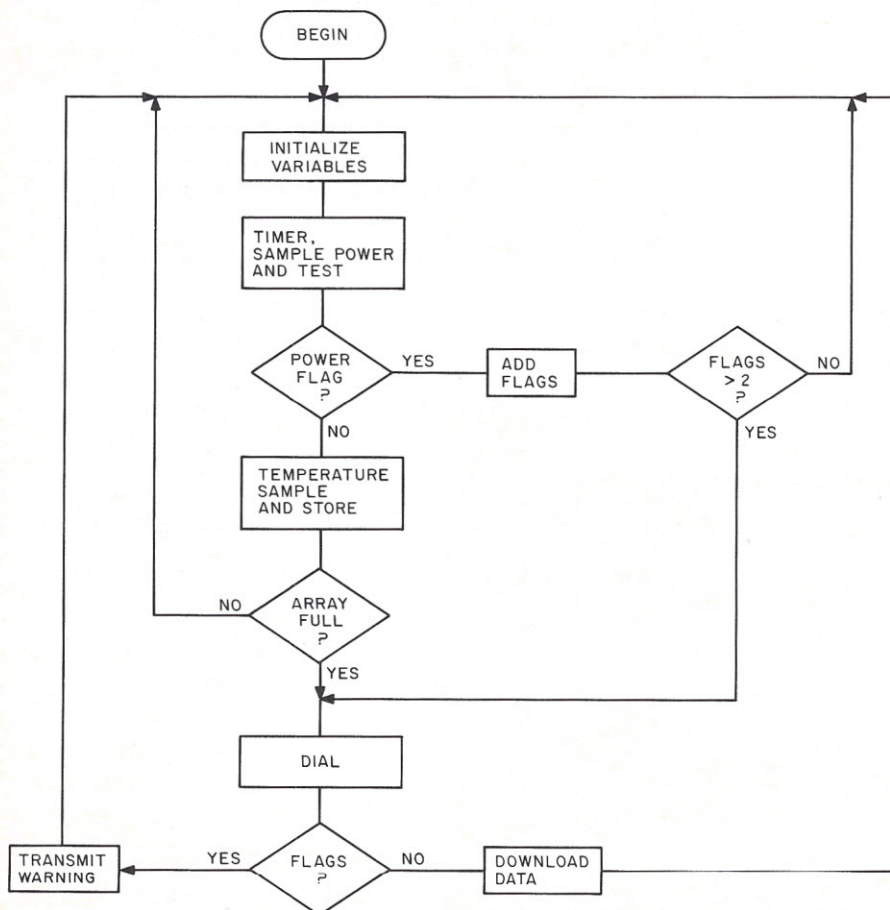


Figure 1. Flowchart for the data acquisition system software.

CONCLUSION

The preceding example demonstrates the simplicity and convenience of system design with the MA2000 family of Macrocomponents. Modular Forth coding allows complementary code and hardware expansion. It is easily conceived that the above system could become a control system merely by integrating a block of code for analog and parallel I/O, then plugging in the appropriate Macrocomponents. The ease of system expansion, in combination with its physical and electronic advantages, make it an ideal solution to system design when space, power, and design time are critical. In fact, its size and power advantages now allow the implementation of previously unrealizable applications and will continue to inspire applications in areas never conceived of as targets for a microprocessor.

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MISSILE SYSTEMS TUCSON

KEEPING THE HERO 1'S STEERING WHEEL STRAIGHT

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This article discusses a way to align the steering/drive wheel of the Heath HERO 1 robot to allow more accurate navigation and path repeatability. The HERO 1 sits on a tri-wheel base and uses a single wheel for both steering and driving. This wheel is located at the forward point of the triangular wheel arrangement and pulls the robot along. Although this approach simplifies certain engineering details, it does have drawbacks.

A sizable percentage of the robot's weight is carried on the steering motor bearing, causing some flexing at that interface. The system is also mechanically "loose" at this point and the weight causes a moment that bends the wheel out of the vertical plane. Bumps and irregularities on the floor surface can also move the wheel sporadically.

An optical encoder on the drive wheel provides feedback for distance repeatability. The steering motor assembly, however, runs open-loop. What is needed is a sensor for the straight-ahead position that can be used for periodic calibration. After this, the navigation inaccuracies can be characterized and software can be used to compensate for the inaccuracies.

We considered several ways to implement this sensor system. One method involved a disk mounted to the steering motor shaft, an index hole at the straight-ahead position, and an optical sensor. Another approach involved a magnetic reed switch mounted on the body and a magnet on the rotating drive assembly. A third possibility was a microswitch on the

```

;STRAIGHT-AHEAD DEMO PROGRAM
;VERSION 1.2 JULY 83
;CPU '6800'

;
;
;
0000 = 0100      ORG $0100
0100 DC08FO      DB $0DC, $08, $FO ;DRIVE FORWARD SLOWLY
                                ;RELATIVE $FO STEPS
                                ;CONTINUE WITH PROGRAM
                                ;
0103 BD0109      JSR STEER        ;CHECK STEERING POSITION
                                ;
0106 1CFB        DB $1C, $0FB     ;BRANCH TO STEER SUBROUTINE
                                ;IF STILL DRIVING FORWARD
                                ;
0108 3A          DB $3A           ;RETURN TO EXECUTIVE PROGRAM
                                ;
                                ;SUBROUTINE TO NULL STEERING
                                ;
                                ;SENSOR EQU $C2A0
0109 86EC        STEER: LDA A #$0EC ;STEERING MOTOR, SLOW, CLOCKWISE
010B B7011C      STA A DIR
010E B6C2A0      LDA A SENSOR
0111 8401        AND A #$01       ;LSB MASK
0113 16          TAB             ;SAVE STATE
0114 2705 ^011B  BEQ MOVE        ;IF 0 THEN GO CLOCKWISE
0116 86E8        LDA A #$E8       ;IF 1 THEN GO COUNTERCLOCKWISE
0118 B7011C      STA A DIR
                                ;
011B D3          MOVE: DB $0D3    ;MOVE MOTOR, WAIT, REL, IMMEDIATE
011C EC          DIR:  DB $0EC    ;STEER, SLOW
011D 01          DB $01          ;ONE STEP
                                ;
011E B6C2A0      LDA A SENSOR
0121 8401        AND A #$01
0123 11          CBA             ;CHANGE IN SENSOR?
0124 27F5 ^011B  BEQ MOVE        ;IF SENSOR IS SAME, KEEP GOING
                                ;
0126 8649        LDA A #$49
0128 9706        STA A #06       ;ELSE UPDATE NULL COUNT
                                ;
012A 8F0010      DB $8F, $00, $10 ;PAUSE FOR 1 SECOND
012D 39          RTS
012E            END

```

Listing 1. A demonstration program for the wheel straight-ahead sensor. This program must be run in the Robot Interpreter Language that recognizes 6800 commands as a subset. Robot Interpreter commands are placed in *define byte* (DB) statements. This program was assembled using a Sorcim 6800 Assembler, Version 3.5F.

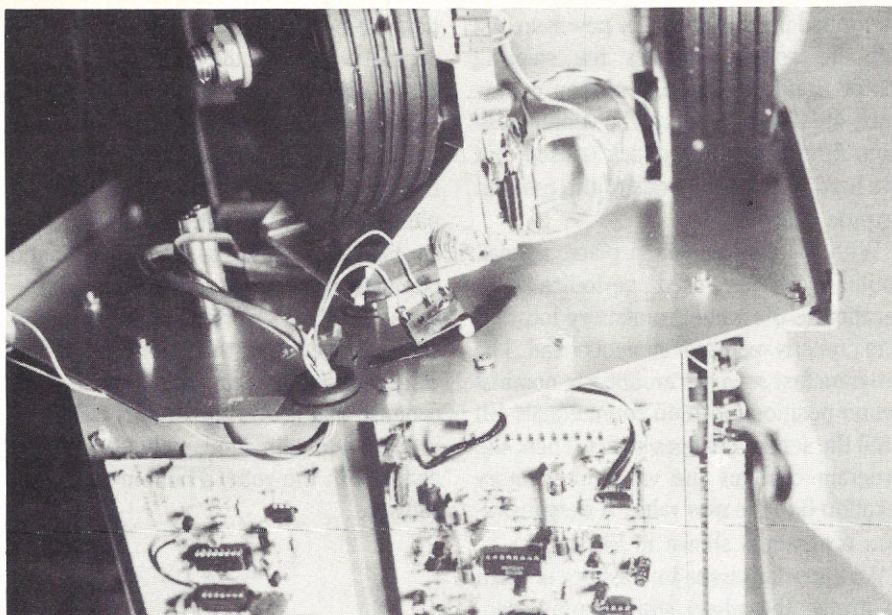


Photo 1. The underside of a Heath HERO 1 ET-18 robot showing the microswitch mounted on the steering wheel assembly and the semicircular track used to activate the switch.

moving assembly with a trip on the fixed assembly. This latter approach, which seems to be the simplest, is discussed here.

The simplest method is to mount a microswitch on the moving assembly and a screw through the base plate. As the

microswitch moves over the screw, it will be activated. This signal can then be read by the onboard control computer. The screw and switch must be placed in positions that represent a head-on condition for the drive wheel.

After using this arrangement for some time, it became apparent that we could find the head-on position much faster if the wheel's direction and position were known. We tried two different algorithms for finding an unknown point by starting at an unknown location. One algorithm used a spiral search from the current position, alternately searching left and right by ever-increasing distances. A second approach was to go to one of the drive wheel's known end stops and then search backwards. Neither approach is desirable for "on-the-move" operation and each can take a long time before finding the straight-ahead point.

This problem can be overcome by using the microswitch to indicate on which side of the straight-ahead point the wheel is currently located. By having the microswitch change states at the straight-ahead point, the software can determine in which direction the wheel must be steered to reach that position. This ability can be added to the simple microswitch arrangement by attaching a semicircular track to the robot base and having the microswitch ride along the track. The track should be high enough to activate the switch.

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The track and switch arrangement is shown in Photo 1. The semicircular track covers half of the wheel's travel distance and starts at precisely the straight-on wheel position. The switch is set up to ground the least significant bit (LSB) of the HERO 1's experiment board input port. Although this is sufficient for development purposes, a final version should probably use another input port.

SOFTWARE

It is very simple to write a software routine which looks at the state of the microswitch, determines in which direction the straight-ahead point is located, and then moves in that direction one step at a time until the state of the microswitch changes. However, the straight-ahead sensor can be much more useful.

A number indicating the steering motor position is contained in memory location 6. This value ranges from 00 (full left) to hexadecimal 93 (full right). During the HERO 1's automatic calibration sequence,

performed immediately after power-up, the onboard software rotates the steering motor against the stop, and then counts back 49H steps to reach the center position. After this, no feedback is used, but the hard stops at the ends of the rotation provide overrides.

With the new sensor in place, a small routine can be used periodically to recalibrate the value in memory location 6 to properly represent straight-ahead. The program first searches around the nominal center position (position count equals 49) until the sensor changes states. Then, the program changes the value in memory location 6 to the new value. A demonstration program is shown in Listing 1.

An important issue to consider is when to invoke the wheel straightening algorithm. Since the HERO 1 does not have built-in wheel position feedback, you must invoke the centering and adjusting algorithm yourself. The demonstration program uses a *motor continue* command to drive the robot forward while periodically searching for the straight-ahead while in motion. If you are using an external naviga-

tion reference such as infrared seeking, the control program could be used to automatically invoke the recalibration routine if excessive steering corrections are required.

The ideal is to add position feedback on the steering axis. This could be implemented with an optical disk and sensor like the one used as a tachometer and odometer on the drive wheel. Unfortunately, the HERO 1's standard software is not set up to recognize this information. The wheel straight-ahead sensor is a compromise that allows corrections for errors in the motion direction, without requiring changes in the robot's built-in operating software.

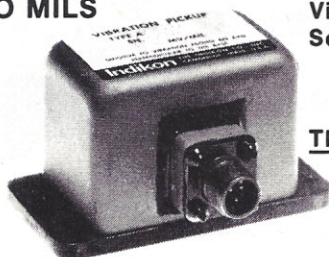
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A THIRD-GENERATION STEPPER MOTOR CONTROLLER

PART II

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COMMUNICATIONS AND SYNCHRONIZATION

Most stepper motors are just one part of a functional system. These systems often must synchronize the various subsystems with each other or with a real-world occurrence. The CY525 is designed with both signal emitters and detectors to simplify synchronization with neighboring (interacting) subsystems.

The CY525 motor interface is very simple, consisting of six output signals. Since the controller is designed for four-phase motors, a signal line is provided for each phase as shown in Figure 7. The patterns necessary for motor operation, including direction sequencing, appear on the phase outputs. A simple L/R-type driving circuit can be connected directly to the phase outputs to run the stepping motor. Alternatively, the CY525 pulse and direction outputs could be used to drive a more sophisticated pulse-to-step translator. The Pulse line gives one pulse at the beginning of each step and the Direction line always indicates the current stepping direction.

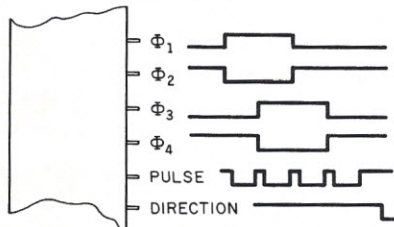


Figure 7. The stepper motor interface consists of six pins: the four phase controllers, the pulse line, and the direction indicator.

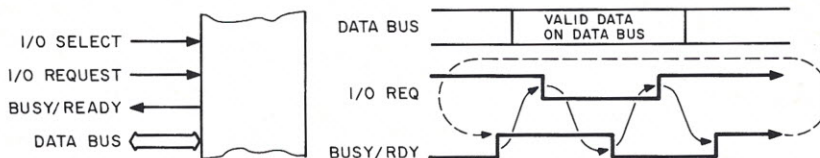


Figure 8. Data interface and handshake waveform.

The CY525 data interface shown in Figure 8 is also very simple. Commands and parameters are passed from the command source to the CY525 on a bidirectional 8-bit parallel data bus. Data direction is determined by the I/O Select line which allows the CY525 to receive commands and also transmit current parameter values.

Data transfer is controlled by a standard two-line handshake protocol. The control processor waits for the CY525 Busy/Ready line to go high, indicating that the CY525 is ready for the next command byte. The control processor then places data on the bus and indicates that the data is available by changing the I/O Request line from high to low. Data must remain stable until the CY525 indicates that the data is accepted by a high-to-low transition of the Busy/Ready line. During this busy time, the CY525 is processing the received character. The master processor then changes the I/O Request line from low to high and waits until the CY525 is ready for the next data byte.

Data transfers from the CY525 to the master processor are handled in a similar

manner. The master controller uses the I/O Request line to request the next byte and uses the Busy/Ready line to indicate when data is available.

The CY525 has a number of secondary input and output control lines which may be used to modify and control the device's stepping behavior or to indicate certain controller conditions. Two inputs directly affect stepping behavior. The controller will not step while the Step Inhibit line is high. Stepping is resumed when the line goes low again. This signal line may be used to halt motion under emergency conditions, or to slow the step rate if the motor cannot keep up. The Abort signal causes the motor to decelerate to the starting rate.

Two other inputs modify program execution. The Wait line is used to suspend program execution until the signal level on that line is in a certain state. Program commands allow the program to wait for either a high or low signal, making it possible to synchronize on either line transition. The Dowhile input line is used with the conditional loop command. While the line is low, the CY525 loops back to a specified program location, repeating the program sec-

tion over and over. The controller continues with the rest of the program after the line goes high.

The CY525 also provides a number of output signals which may be used by other parts of the system. While stepping, the Slew line indicates that the CY525 has reached the maximum programmed step rate and is not accelerating or decelerating. When the CY525 has stepped for the specified number of steps, the Motion Complete signal indicates the end of the current motion. The Run signal indicates when a program is executing. In addition, the CY525 provides an uncommitted output—Programmable Output—which can be used for any digital control purpose. The level on this output is controlled by two commands, one for a high output and the other for a low output.

Phase Signals. The table and waveform shown in Figure 9 indicate the sequential values assumed by the stepper drive signals. The table also indicates how the step patterns correspond to the offset parameters 0 through 3 specified by the OFFSET(n) command. Note that the OFFSET command sets the internal step pattern pointer to the value specified by the indicated parameter and that the pulses appear on the drive signal lines. An offset parameter of 4 causes all phase lines to go high with no pulse, while a parameter of 128 causes all the phases to go high with a pulse on pin 35.

Continuous Step Operation. The CY525 provides for continuous, unlimited stepping. This mode is enabled via the H instruction. H stands for Halt mode since the CY525 will step until halted by the Abort line (pin 6). The H command does not initiate stepping, it merely sets an internal flag that is tested during execution of any motion command. The H instruction must be issued for every continuous stepping command, since the halt mode flag is reset when the continuous motion is aborted. The following example illustrates this point:

```
N 1000<CR> ;set number of steps
G<CR>       ;take 1000 steps and stop
H<CR>       ;set continuous step
              mode
G<CR>       ;ramp up and step un-
              til halted
G<CR>       ;take 1000 steps and
              stop
```

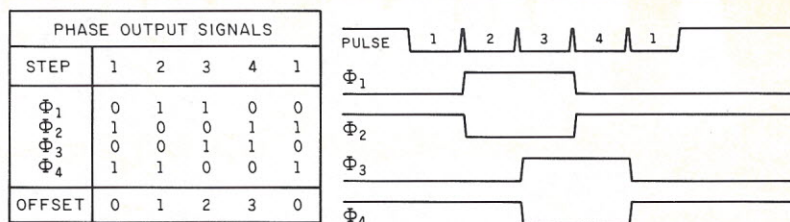


Figure 9. Phase step control outputs.

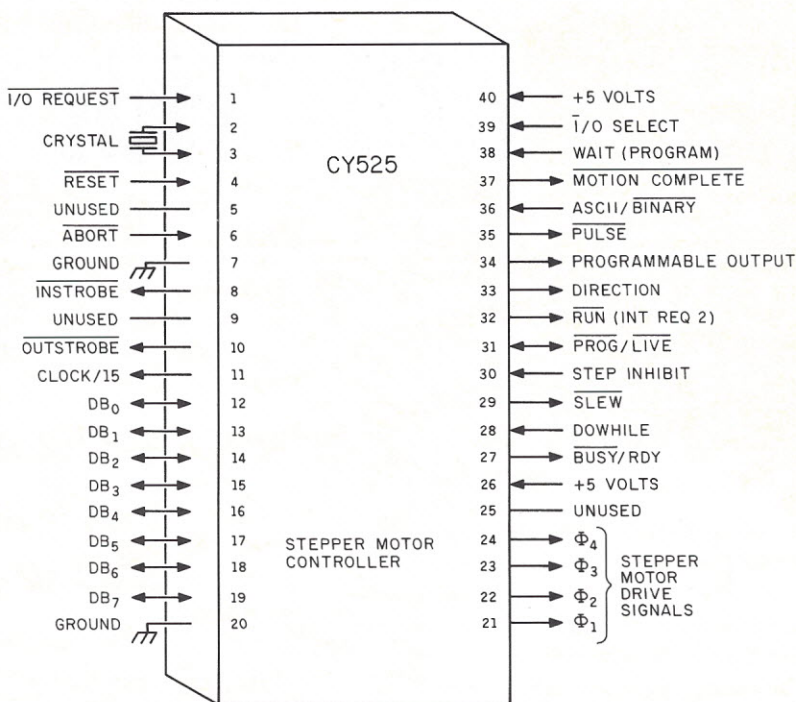


Figure 10. The CY525 pinout diagram.

The Abort line is used to halt the continuous stepping that occurs when a Go command (G) is preceded by the halt mode command (H). The Abort line should be brought low and held low until the Motion Complete signal indicates successful completion. To summarize: Normal CY525 motions terminate at the specified target position (or after N steps). Continuous step operation uses no target position and terminates when the Abort line is pulled low and held low until the Motion Complete signal (pin 37) goes low.

Slew Line. The Slew line (pin 29) indicates when the CY525 is stepping at a steady rate. This line is high during both up ramp and down ramp excursions. It changes to a low signal once acceleration and deceleration are complete. The normal operation mode activates the Slew line when the maximum step rate is reached. It returns high when the CY525 begins ramping down.

The meaning of *slew* is more general in the continuous step mode. In this mode, the Slew line indicates when the CY525

has completed ramping and is moving at a steady rate, not necessarily the maximum rate. Thus, when the rate is changed on the fly, the CY525 raises the Slew line while accelerating or decelerating to the new rate, then lowers it when the new rate is reached. This procedure is shown in Figure 11.

Rate Changes. The CY525 can specify rate changes while the motor is stepping. This allows much more complex motion profiles and closer motor movement control. Two conditions must be met to use this feature:

- Continuous step mode must be invoked via the H command
- The Slew line should be low, indicating steady stepping (not ramping).

Once these conditions are met, the step rate can be changed as follows:

1. Place the new 8-bit binary rate on the CY525 bus.
2. Lower the I/O Request line (pin 1) to the CY525.
3. Raise the I/O Request line when the Slew line goes high.

The CY525 will now ramp up or down as appropriate until the new rate is reached and then continue at this rate until changed again or aborted. An example of this is shown in Figure 12.

PROGRAMMING EXAMPLE

In the accompanying welding machine example, relative mode stepping is used to move a welder from one spot to the next while absolute mode stepping is used to bring the welder back to the home position, ready to start the next workpiece. The Wait line is used to indicate that a workpiece is in position, and the Dowhile line indicates when there are no more pieces to weld. A real application may be more complex than this illustration, but the program indicates the level of problems which the CY525 can solve without help from a host computer. This program uses 20 of the 60 available bytes in the CY525 program buffer.

Note that labels B\$ and C\$ allow a program branch to be made without the necessity of counting bytes to determine the actual location of the target instruction in the program buffer. The labels can be any of the five allowed label characters in any order. Also note that labels do not require any extra bytes in the program buffer.

COORDINATING SEVERAL CY525s

Multiple CY525s may be synchronized by using the Programmable Output line, the Wait functions, Dowhile signal, and time delays. These may also be combined with other signals, such as Direction, Slew, and Motion Complete which are used to select the point in the motion when the signal is presented to the waiting controller.

Consider a general parts-handling function in which the part must be handed off between two controllers. The geometry of the parts and the arms used to carry the parts requires that the hand-off be carefully synchronized between the two controllers. The controller receiving the part waits at the receiving position until the CY525 which has the part signals it has arrived. The two arms then move together in a coordinated motion, reaching a point at which the distance between them is minimal. The part is exchanged and the arms move apart, again in a coordinated motion. Once a certain position is reached, the arms are free to move independently, and continue with their assigned programs.

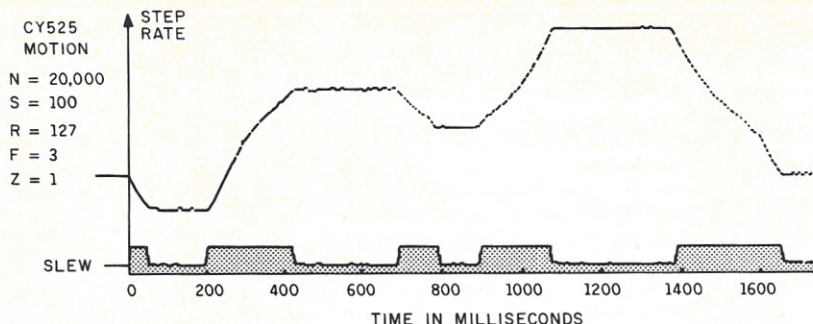


Figure 11. This graph illustrates the Slew operation in continuous step mode when rate changes are executed on-the-fly.

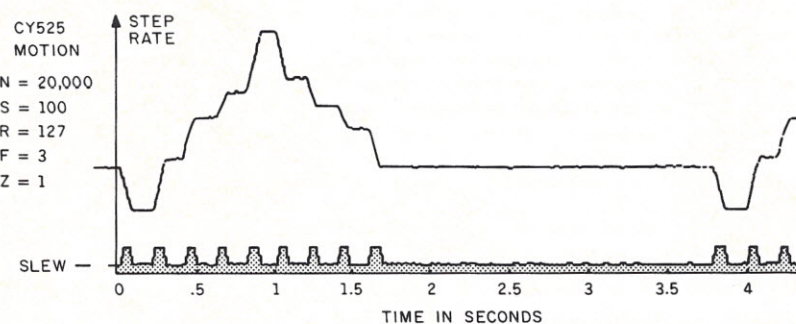


Figure 12. Typical slew and stepping rate profiles for on the fly changes.

Welding Machine Example

Suppose we want a row of six equally spaced welds on a piece of metal. The welder should be turned on by the CY525 Programmable Output line when in position, and be turned off when finished. After completing six such welds, it will return as quickly as possible to its starting position, and wait for the next workpiece to come into position. It will then weld the next six spots, and continue in this manner until there are no more pieces to weld, at which time the program will stop and the CY525 will return to the command mode.

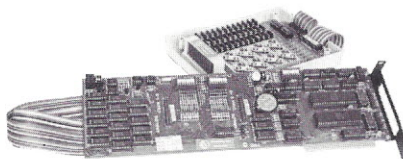
R 120<CR>	
S 80<CR>	Define stepping parameters
F 9<CR>	
A 0<CR>	Declare current position as home
E<CR>	Enter and save the following program
B\$N 20<CR>	Take 20 steps between welds
+<CR>	Clockwise direction
W<CR>	Wait until workpiece ready
C\$G<CR>	Go 20 steps
C<CR>	Activate welder
D 1000<CR>	Delay 1000 ms (1 second) to weld
B<CR>	Turn off welder
L 6,C<CR>	Repeat six times from G command
P 0<CR>	Return to home position after six welds
T B<CR>	Repeat program until no more pieces
O<CR>	Stop program, return to command mode
Q	Exit program mode
X<CR>	Begin executing program

New Products

Data Acquisition Menu System

The Strawberry Tree Computers data acquisition system is set up in menus in a few minutes rather than by writing programs. The Analog Connection accepts input signals of all types at convenient screw terminals. Operating in an IBM PC or Apple IIe computer, it accepts 8 or 16 inputs from temperature, pressure, strain, voltage, and current sensors without adding interface modules. It logs data, including maximum, minimum, average, and difference, on a printer or disk. It sounds alarms and controls equipment such as heaters and motors at levels entered in menus. It senses digital inputs from switches or logic signals.

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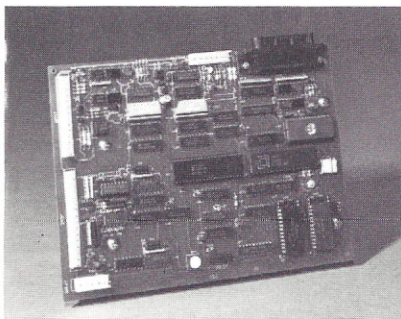
Control and Robotics Manual

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For more information, contact: F. Kaplan, Compusa Corp., 1101 Bristol Rd., Mountainside, NJ 07092, telephone (201) 654-7220.

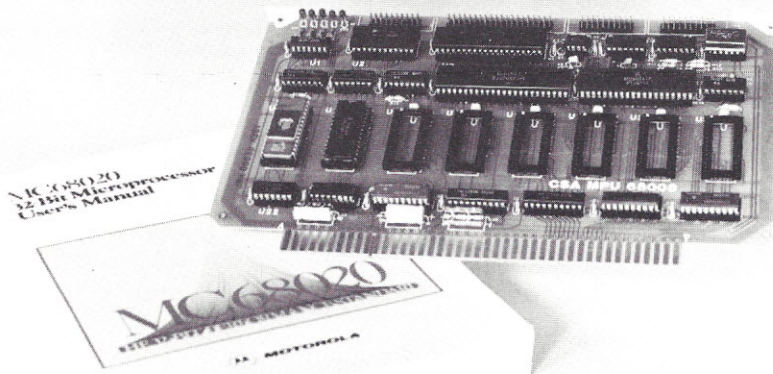
Circle 31

Motion Control Board



Delta Tau Data Systems, Inc. announces the MINI MC², a stand-alone motion control card that can be integrated into new or existing robots or machines and can be expanded to drive up to eight axes under control of a personal or other programmable computer. Commands are sent to the motion control card using simple ASCII characters transmitted over a parallel port, optional RS-232 port or IEEE-488 bus. The control card fits into an industry standard servoamplifier chassis slot. High-speed operation of 200,000 encoder counts per second, with linear and circular interpolation, is handled. The position, velocity, acceleration, and gains are programmable using the 480 program step motion buffer on the card. Loops and multilevel motion subroutines may be implemented. Hydraulic or DC servomotors are controlled with or without a tachometer loop.

Small quantity price for the MINI MC² is below \$700. For more information, contact: Delta Tau Data Systems, Inc., Canoga Park, CA 91304, telephone (818) 998-2095. Circle 32



68000 Exorciser Board

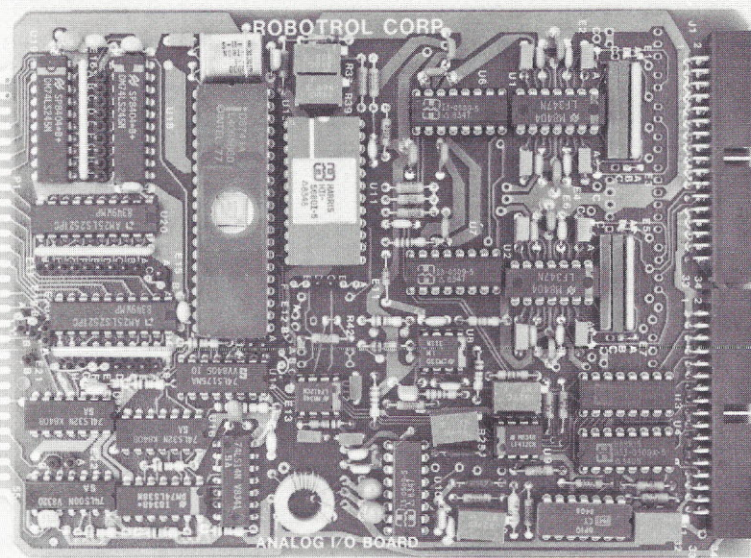
Designed to plug into any Motorola Exorbus system, this 68000 board uses the Motorola 68008 microprocessor. The 68008 runs the full 68000 (and 68020) instruction set and directly interfaces 8-bit peripherals and memory. On-board, interchangeable 64 Kbyte programmable and read-only memory using 2764/6264 devices is provided. A timer and dual RS-232 ports are provided by a 68681 DUART. A 16-bit parallel

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For more information, contact: Roger Brokaw at Computer Systems Associates, Inc., 7564 Trade St., San Diego, CA 92121.

Circle 33

New Products



Robotrol Analog I/O

The RSD-7518 from Robotrol Corp. is an intelligent multifunction analog I/O board compatible with the STD-Bus. The RSD-7518 has four differential and eight single-ended analog inputs and eight analog outputs. The gain of the differential inputs is resistor programmable from X1 to X1000 and the gain of the single-ended inputs is resistor programmable from X1 to X10. The resolution of all inputs and outputs is 12 bits.

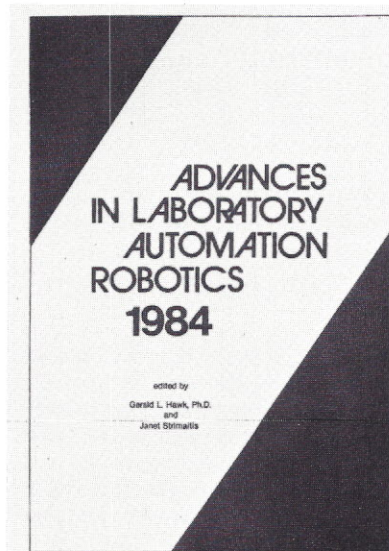
The RSD-7518 features 12 programmable modes (six output and six input) with programmable interval timing; four differential inputs; eight single-ended inputs; eight independent out-

puts; 12-bit resolution on all inputs and outputs; memory- or I/O- mapped bus interface; and vectored interrupt or polled program operation. The programmable features include collecting multiple samples in single or multiple channels, sample averaging, and determining sample maximums and minimums when averaging.

Prices start at \$595 (quantity 1) and delivery is two weeks ARO. For further information, contact: Paul Anderson, Robotrol, Corp., 16100 Caputo Dr., Morgan Hill, CA 95037, telephone (408) 778-0400.

Circle 35

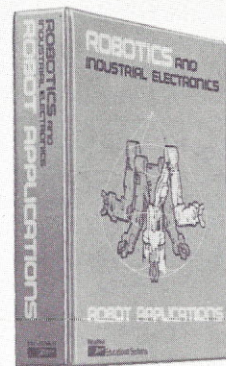
Laboratory Proceedings



Advances in Laboratory Automation—Robotics 1984, edited by Gerald Hawk, gathers 35 presentations using laboratory robotics to automate analyses in several types of laboratories: pharmaceutical, food/beverage, chemical, petrochemical, biotechnical, and clinical research. The papers were originally presented at the International Symposium on Laboratory Robotics sponsored by Zymark Corp. The papers cover a broad interdisciplinary range of topics on the application of robotic technology to laboratory automation. Written by an international group of expert contributors, the papers show use of laboratory robotics in the following areas: analytical chemistry, biochemistry, radiochemistry, methods development, biotechnology, materials testing, pharmaceutical QA and QC, and microbiology.

Advances in Laboratory Automation—Robotics 1984 is available for \$45 from Zymark Corp., Zymark Center, Hopkinton, MA 02748.

Circle 36



Robot Applications

A new Robot Applications course designed to teach the concepts and technologies that are shaping today's robot industry is available from Heathkit/Zenith Educational Systems. The course briefly reviews the basic concepts of robotics and then introduces new ideas and technologies that are being used to create the robots of the future. The factors which govern the selection of an industrial robot (tasks involved, payback, reliability, quality) are covered with particular emphasis given to different types of vision, tactile, and environmental feedback sensor systems. The course also covers present and future robot applications, computer-aided manufacturing, and nine hands-on course experiments which can be performed using HERO I. These experiments include constructing a variety of sensor systems.

For more information about the Robot Applications course, write: Heath Co., Dept 570-435, Benton Harbor, MI 49022.

Circle 34

Parallel Heath

Dayco Enterprises announces the release of a parallel I/O kit for Heath's HERO I robot. The kit provides the HERO I with a total of 16 memory-mapped input or output lines. Any I/O configuration can be programmed. Typically, this means that all 16 lines can be specified as either input or output or eight lines can be specified as input and eight specified as output, etc.

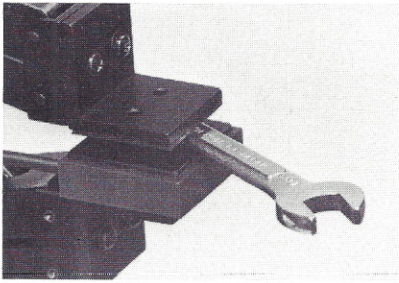
The kit provides for full interrupt handling and can be software driven to allow full handshaking and device polling. A total of four interrupt lines are provided. The kit requires no modification of the HERO I and can be easily fitted to the existing robot. Full documentation is provided.

The cost of the kit is \$39. For more information, contact: Dayco Enterprises, Box 3374 Clearwater, BC V0E 1N0 CANADA, telephone (604) 587-6415.

Circle 37

New Products

Robot Feelers



Tactile Robotic Systems has introduced a tactile sensing system for the robotics industry. Using state-of-the-art sensing technology and artificial intelligence, the tactile sensor will allow robots to determine the size, shape, and orientation of parts in its grip. This system will give robots the ability to perform sophisticated assembly operations such as circuit board and hybrid assembly, wafer fabrication, and various material handling operations. In many applications, this new tactile sensing system will be able to replace expensive vision systems; performing the same tasks at a greatly reduced cost. The sensor will also be able to work with vision systems to perform various complex tasks that have yet to be mastered by robots. With the addition of tactile sensing, less robot position accuracy will be required. This will mean a less costly robot and a faster cycle time. The sensor itself is a 256-point, 16 by 16 sensitive array. Total cost of the tactile sensing system including interface is approximately \$2,500.

For more information, contact: Tactile Robotic Systems, 1172-D Aster Ave., Sunnyvale, CA 94086, telephone (408) 241-1520. Circle 38

Apple Digital I/O

Control Ware introduces its Digital I/O Board for the Apple II. It features 16 inputs, 16 buffered outputs, and a one-byte input. Uses include robotics, industrial, and home control. No setup software is required, resulting in easy programming. Each of the 16 inputs has its own memory address, so no bit-testing software is required. Each of the 24 input lines has its own pull-up resistor, allowing TTL circuits or switches to act as inputs. The price is \$89.

Other features include socketed ICs, interrupt request (IRQ) and nonmaskable interrupt (NMI) lines available on the input connector, USR1 solder pad, 120-day warranty, sample programs, and manual.

For more information, contact: Control Ware, PO Box 1467, Oak Brook, IL 60521, telephone (312) 530-4110. Circle 41



New Size 23 Stepper

Clifton Precision, Litton Systems, Inc., has introduced a new series of size 23 1.8 degree stepper motors. They offer up to 125 oz-in. holding torque and 94 oz-in. dynamic torque in a package with overall length (excluding shaft) which can be as short as 1.5 in. Their low noise makes them useful in office equipment and they are ideal for robotics and machine tool applications. The motors offer 200 steps per revolution, fast damping for better control, and high torque and reliability.

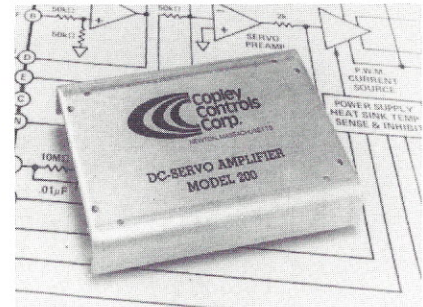
For additional information, contact: Jim Chandler, Clifton Precision, PO Box 160, Murphy, NC 28906, telephone (704) 837-5115.

Circle 39

HS/FORTH

HS/Forth is an advanced Forth interpreter optimized for the IBM PC and MS-DOS machines. Forth-79 or 83 Standard programs often execute twice as fast as under other Forth systems—including those limited to 64 Kbytes. Programs can occupy your full memory space with little or none of the space and execution time overhead usually needed by systems capable of executing programs larger than 64 Kbytes. Like other Forths, HS/Forth provides interactive program development superior to BASIC, compact code, and convenient machine and peripheral control. Program entry is simplified by a resident command editor and input logger. Headers can be eliminated at any time without recompiling. High-level Forth words can execute from within machine code primitives, a plus for interrupt and exception handlers and debugging utilities.

HS/Forth includes utility files to read, write, and load standard MS-DOS files, standard screens, and screens mapped onto random access files. Other utilities include segment management, graphics, software and 8087 floating point, string functions, program editor, and music. The music utility demonstrates a background multitasking example.



PWM Servoamplifier

The model 200 and 201 from Copley Controls offers a complete PWM servoamplifier that delivers 5 A peak at 45 V to drive DC motors. The model 200 and 201 feature a 26k Hz switching frequency. This allows the amplifier to be used in applications where acoustic switching noise is a problem and with lower inductance motors without a series choke. The 200 and 201 are intended for driving DC torque motors and linear actuators in robotic, CAD/CAM, machine tool, and military applications. The high-efficiency pulse width modulated design allows for installation where minimum cooling is available.

For more information, contact: Copley Controls Corp., 375 Elliot St., Newton, MA 02164, telephone (617) 965-2410. Circle 40

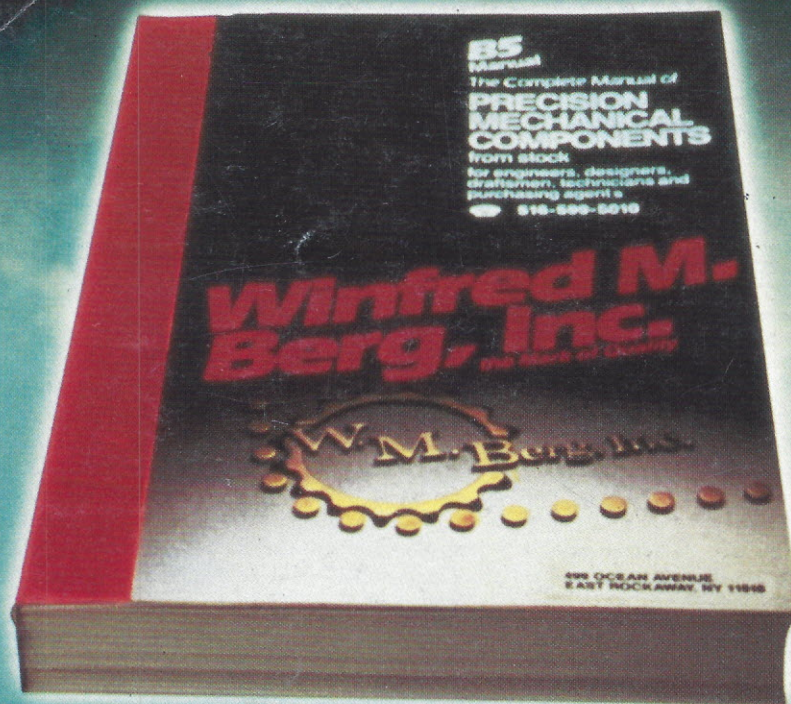
The assembler, which implements the complete 8088/8086 instruction set can create new code primitives or complete stand-alone program files. High-level flow control complements the complete forward and reverse branching capabilities. People unfamiliar with assembly language can use AUTOOPT to create machine code programs that execute half as fast as good assembly language ones and only a little larger. AUTOOPT can be used with the assembler as a macro source. The assembler also supports the 8087 and 80186.

The widely quoted "Sieve of Eratosthenes" benchmark (Byte, January 1983) requires 70 to 140 seconds execution time on various Forths, most of which are limited to 64 Kbyte programs. HS/Forth requires only 47 seconds and with AUTOOPT, a mere 9 seconds. This compares with 5 seconds for optimized machine code and 2000 seconds for interpreted BASIC.

The HS/Forth system requires at least 64 Kbytes of memory, 1 disk drive, and the PC DOS or MS-DOS operating system. HS/Forth, including the AUTOOPT, MICRO-ASM, and utilities, costs \$250. For more information, contact: Harvard Softworks, PO Box 2579, Springfield, OH 45501, telephone (513) 390-2087. Circle 42

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